valuating properties for acquisition, allowing long-term costs associated with BMPs to be factored into the property purchase agreement.

A more extensive discussion of long-term BMP maintenance is included in Section 6.

2.4 Planning Principles

Planning and design for water quality protection employs three basic strategies in the following order of relative effectiveness: 1) reduce or eliminate post-project runoff; 2) control sources of pollutants, and 3) treat contaminated stormwater runoff before discharging it to natural water bodies. See Figure 2-5. These principles are consistent with the typical permit and local program requirements for Priority Projects that require a consideration of a combination of source control BMPs (that reduce or eliminate runoff and control pollutant sources) and treatment control BMPs with specific quantitative standards. The extent to which projects can incorporate strategies that reduce or eliminate post project runoff will depend upon the land use and local site characteristics of each project. Reduction in post project runoff offers a direct benefit by reducing the required size of treatment controls to meet the numeric standard included in the local permit. Therefore, project developers can evaluate tradeoffs between the incorporation of alternative site design and source control techniques that reduce runoff and pollutants, and the size of required treatment controls either included as part of the project or as a commitment to an offsite watershed-based program.

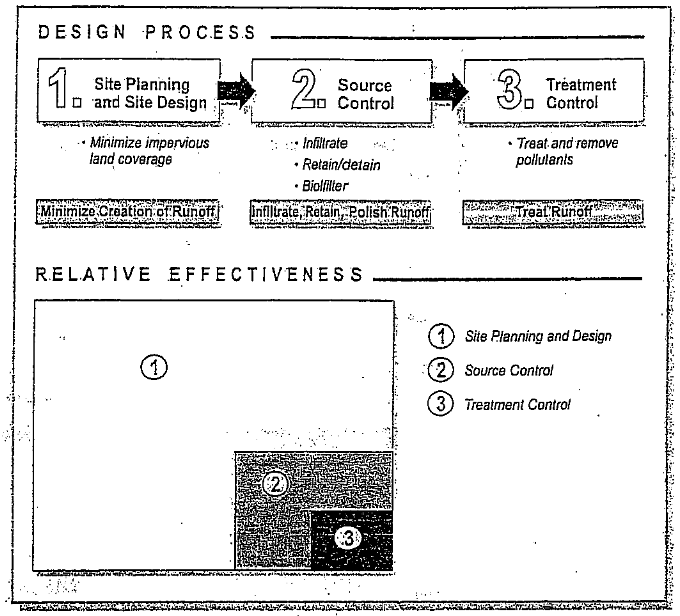

Figure 2-5
Planning Principles

2.4.1 Reduce Runoff

The principle of runoff reduction starts by recognizing that developing or redeveloping land within a watershed inherently increases the imperviousness of the areas and therefore the volume and rate of runoff and the associated pollutant load; and outlines various approaches to reduce or minimize this impact through planning and design techniques.

The extent of impervious land covering the landscape is an important indicator of stormwater quantity and quality and the health of urban watersheds. Impervious land coverage is a fundamental characteristic of the urban and suburban environment -- rooftops, roadways, parking areas and other impenetrable surfaces cover soils that, before development, allowed rainwater to infiltrate.

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Without these impervious coverings, inherent watershed functions would naturally filter rainwater and prevent receiving water degradation. Impervious surfaces associated with urbanization can cause adverse receiving water impacts in four ways:

- Rainwater is prevented from filtering into the soil, adversely affecting groundwater recharge and reducing base stream flows.
- Because it cannot filter into the soil, more rainwater runs off, and runs off more quickly, causing increased flow volumes, accelerating erosion in natural channels, and reducing habitat and other stream values. Flooding and channel destabilization often require further intervention. As a result, riparian corridors are lost to channelization, further reducing habitat values.
- Pollutants that settle on the impervious pavements and rooftops are washed untreated into storm sewers and nearby stream channels, increasing pollution in receiving water bodies.
- Impervious surfaces retain and reflect heat, increasing ambient air and water temperatures. Increased water temperature negatively impacts aquatic life and reduces the oxygen content of nearby water bodies.

Techniques for reducing runoff range from land use planning on a regional scale by permittees or other local planning agencies, to methods that can be incorporated into specific projects. These techniques include actions to:

- Manage watershed impervious area
- Minimize directly connected impervious areas
- Incorporate zero discharge areas
- Include self-treatment areas
- Consider runoff reduction areas.

Brief summaries of the following techniques are presented:

Manage Watershed Impervious Area

Land use planning on the watershed scale is a powerful tool to manage the extent of impervious land coverage. This planning has two elements. First, identify open space and sensitive resource areas at the regional scale and target growth to areas that are best suited to development, and second, plan development that is compact to reduce overall land conversion to impervious surfaces and reliance on land-intensive streets and parking systems.

Impervious land coverage is a practical measure of environmental quality because:

- It is quantifiable, meaning that it can be easily recognized and calculated.

- It is integrative, meaning that it can estimate or predict cumulative water resource impacts independent of specific factors, helping to simplify the intimidating complexity surrounding non-point source pollution.

- It is conceptual, meaning that water resource scientists, municipal planners, landscape architects, developers, policy makers and citizens can easily understand it.

Water resource protection at the local and regional level is becoming more complex. A wide variety of regulatory agencies, diverse sources of non-point source pollution, and a multitude of stakeholders make it difficult to achieve a consistent, easily understandable strategy for watershed protection. Impervious land coverage is a scientifically sound, easily communicated, and practical way to measure the impacts of new development on water quality.

Impervious area reductions also provide additional benefits such as reduced urban heat island effect, resulting in less energy use to cool structures and more efficient irrigation use by plants. Reductions have also be attributed to more human-scale landscaper and higher property values.

Minimize Directly Connected Impervious Areas (DCIA)

Impervious areas directly connected to the storm drain system are the greatest contributor to non-point source pollution. The first effort in site planning and design for stormwater quality protection is to minimize the "directly connected impervious area (DCIA)" as shown in Figure 2-6.

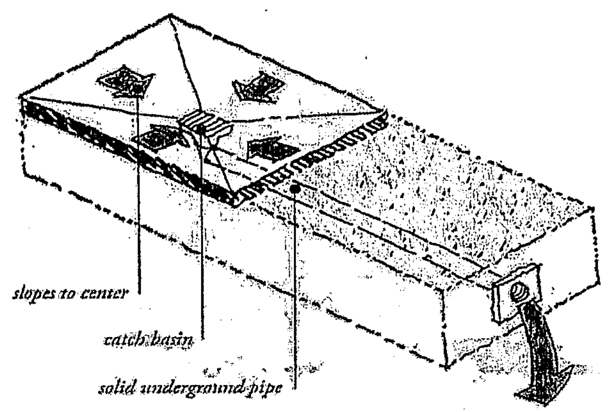

Figure 2-6
Directly Connected Impervious Area

Any impervious surface that drains into a catch basin, area drain, or other conveyance structure is a "directly connected impervious area." As stormwater runoff flows across parking lots, roadways, and paved areas, the oils, sediments, metals and other pollutants are collected and concentrated. If this runoff is collected by a drainage system and carried directly along impervious gutters or in closed underground pipes, it has no opportunity for filtering by plant material or infiltration into the soil. It also increases in speed and volume, which may cause higher peak flows downstream, and may require larger capacity storm drain systems, increasing flood and erosion potential.

Minimizing directly connected impervious areas can be achieved in two ways:

- Limiting overall impervious land coverage

- Directing runoff from impervious areas to pervious areas for infiltration, retention/detention, or filtration

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Strategies for reducing impervious land coverage include:

- Cluster rather than sprawl development
- Taller narrower buildings rather than lower spreading ones
- Sod or vegetative "green roofs" rather than conventional roofing materials
- Narrower streets rather than wider ones
- Pervious pavement for light duty roads, parking lots and pathways

Example strategies for infiltration, retention/detention, and bio-filtration include:

- Vegetated swales
- Vegetated basins (ephemeral- seasonally wet)
- Constructed ponds and lakes (permanent- always wet)
- Crushed stone reservoir base rock under pavements or in sumps
- Cisterns and tanks
- Infiltration basins
- Drainage trenches
- Dry wells
- Others

Unlike conveyance storm drain systems that convey water beneath the surface and work independently of surface topography, a drainage system for stormwater infiltration can work with natural landforms and land uses to become a major design element of a site plan. Solutions that reduce DCIA prevent runoff, detain or retain surface water, attenuate peak runoff rates, benefit water quality and convey stormwater. Site plans that apply stormwater management techniques use the natural topography to suggest the drainage system, pathway alignments, optimum locations for parks and play areas, and the most advantageous locations for building sites. In this way, the natural landforms help to generate an aesthetically pleasing urban form integrated with the natural features of the site.

Incorporate Zero Discharge Areas

An area within a development project can be designed to infiltrate, retain, or detain the volume of runoff requiring treatment from that area.

The term "zero discharge" in this philosophy applies at stormwater treatment design storm volumes. For example, consider an area that functionally captures and then infiltrates the 80th percentile storm volume. If permits require treatment of the 80th percentile storm volume, the area generates no treatment-required runoff.

Site design techniques available for designing areas that produce no treatment-required runoff include:

- Retention/Detention Ponds
- Wet Ponds
- Infiltration Areas
- Large Fountains
- Retention Rooftops
- Green roofs (roofs that incorporate vegetation) and blue roofs (roofs, that incorporate detention or retention of rain).

Infiltration areas, ponds, fountains, and green/blue roofs can provide "dual use" functionality as stormwater retention measures and development amenities. Detention ponds and infiltration areas can double as playing fields or parks. Wet ponds and infiltration areas can serve dual roles when meeting landscaping requirements.

When several "zero discharge" areas are incorporated into a development design, significant reductions in volumes requiring treatment may be realized.

"Zero discharge" areas such as wet ponds, detention ponds, and infiltration areas can be designed to provide treatment over and above the storm volume captured and infiltrated. For example, after a wet pond area has captured its required storm volume, additional storm volume may be treated via settling prior to discharge from the pond. In this case, the "zero discharge" area converts automatically into a treatment device for runoff from other areas, providing settling for storm volumes beyond treatment requirements. Another example is a grassy infiltration area that converts into a treatment swale after infiltrating its area-required treatment volume. The grassy infiltration area in this example becomes a treatment swale for another area within the development.

Figure 2-7 illustrates a residential tract, and a tract incorporating Zero Discharge Area techniques (infiltration areas). The Zero Discharge Area designed tract represents a design to infiltrate (i.e., achieve zero discharge from) a portion of the tract's runoff, reducing total runoff from the tract.

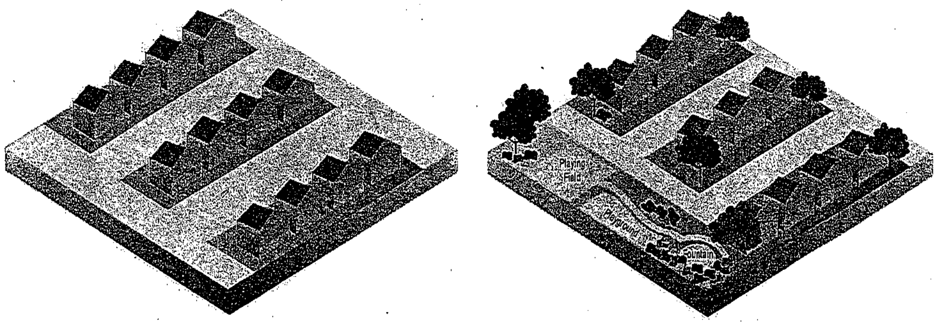

Figure 2-7
Zero Discharge Area Usage

Include Self-Treatment Areas

Developed areas may provide "self-treatment" of runoff if properly designed and drained.

Self-treating site design techniques include:

- Conserved Natural Spaces
- Large Landscaped Areas (including parks and lawns)
- Grass/Vegetated Swales
- Turf Block Paving Areas

The infiltration and bio-treatment inherent to such areas provides the treatment control necessary. These areas therefore act as their own BMP, and no additional BMPs to treat runoff should be required.

As illustrated in Figure 2-8, site drainage designs must direct runoff from self-treating areas away from other areas of the site that require treatment of runoff. Otherwise, the volume from the self-treating area will only add to the volume requiring treatment from the impervious area.

Likewise, under this philosophy, self-treating areas receiving runoff from treatment-required areas would no longer be considered self-treating, but rather would be considered as the BMP in place to treat that runoff. These areas could remain as self-treating, or partially self-treating areas, if adequately sized to handle the excess runoff addition.

Consider Runoff Reduction Areas

Using alternative surfaces with a lower coefficient of runoff or "C-Factor" may reduce runoff from developed areas. The C-Factor is a representation of the surface's ability to produce runoff. Surfaces that produce higher volumes of runoff are represented by higher C-Factors, such as impervious surfaces. Surfaces that produce smaller volumes of runoff are represented by lower C-Factors, such as more pervious surfaces. See Table 2-2 for typical C-Factor values for various surfaces during small storms.

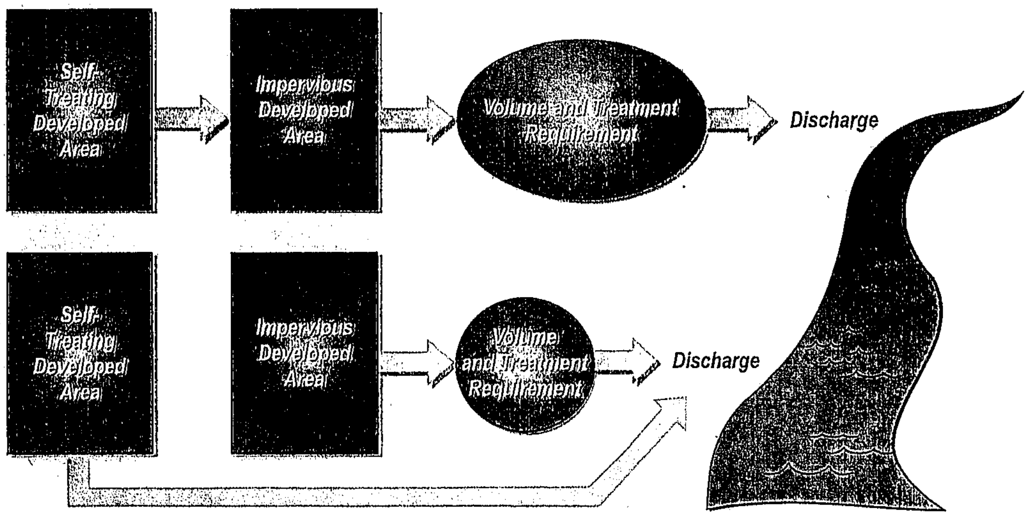

Figure 2-8
Self-Treating Area Usage

Table 2-2 Estimated C-Factors for Various Surfaces During Small Storms

Paving Surface	C-Factor
Concrete	0.80
Asphalt	0.70
Pervious Concrete	0.60
Cobbles	0.60
Pervious Asphalt	0.55
Natural Stone without Grout	0.25
Turf Block	0.15
Brick without Grout	0.13
Unit Pavers on Sand	0.10
Crushed Aggregate	0.10
Grass	0.10
Grass Over Porous Plastic	0.05
Gravel Over Porous Plastic	0.05

Note: C-Factors for small storms are likely to differ (be lower) than C-Factors developed for large, flood control volume size storms. The above C-Factors were produced by selecting the lower end of the best available C-Factor range for each paving surface. These C-Factors are only appropriate for small storm treatment design, and should not be used for flood control sizing. Where available, locally developed small storm C-Factors for various surfaces should be utilized.

Table 2-3 compares the C-Factors of conventional paving surfaces to alternative, lower C-Factor paving surfaces. By incorporating more pervious, lower C-Factor surfaces into a development (see Figure 2-9), lower volumes of runoff may be produced. Lower volumes and rates of runoff translate directly to lower treatment requirements.

Table 2-3 Conventional Paving Surface Small Storm C-Factors vs. Alternative Paving C-Factors

Conventional Paving Surface C-Factors	Reduced C-Factor Paving Alternatives
Concrete Patio/Plaza (0.80)	Decorative Unit Pavers on Sand (0.10)
Asphalt Parking Area (0.70)	Turf Block Overflow Parking Area (0.15)
	Pervious Concrete (0.60)
	Pervious Asphalt (0.55)
	Crushed Aggregate (0.10)

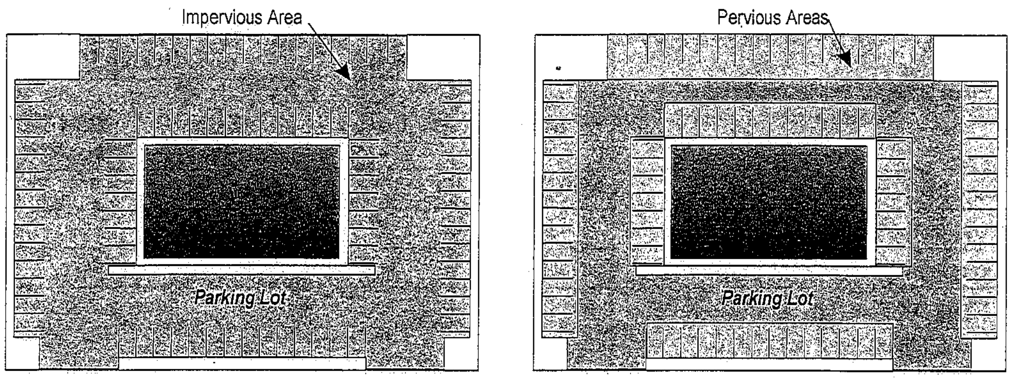

Figure 2-9
Impervious Parking Lot vs. Parking Lot with Some Pervious Surfaces

Site design techniques that incorporate pervious materials may be used to reduce the C-Factor of a developed area, reducing the amount of runoff requiring treatment. These materials include:

- Pervious Concrete
- Pervious Asphalt
- Turf Block
- Brick (un-grouted)
- Natural Stone
- Concrete Unit Pavers
- Crushed Aggregate
- Cobbles
- Wood Mulch

Other site design techniques such as disconnecting impervious areas, preservation of natural areas, and designing concave medians may be used to reduce the overall C-Factor of development areas.

Table 2-4 presents a list of site design and landscaping techniques and indicates whether they are applicable for use in Zero Discharge Areas, Self-Treating Areas, and Runoff Reduction Areas. Several different techniques may be implemented within the same design philosophy. Some techniques may be used to implement more than one design philosophy. Where feasible, combinations of multiple techniques may be incorporated into new development and redevelopment projects to minimize the amount of treatment required.

Table 2-4 Site Design and Landscaping Techniques

Site Design and Landscape Techniques	Design Criteria		Design Philosophy		
	Volume-Based Design	Flow-Based Design	Zero Discharge	Self – Treating	Runoff Reduction
Permeable Pavements					
Pervious concrete	X				X
Pervious asphalt	X				X
Turf block	X			X	X
Un-grouted brick	X				X
Un-grouted natural stone	X				X
Un-grouted concrete unit pavers	X				X
Unit pavers on sand	X				X
Crushed aggregate	X				X
Cobbles	X				X
Wood mulch	X				X
Streets					
Urban curb/swale system	X	X			X
Rural swale system	X	X			X
Dual drainage systems	X	X			X
Concave median	X	X	X		X
Pervious island	X	X			X
Parking Lots					
Hybrid surface parking lot	X				X
Pervious parking grove	X				X
Pervious overflow parking	X			X	X
Driveways					
Not directly connected impervious driveway		X			X
Paving only under wheels	X			X	X
Flared driveways	X				X
Buildings					
Dry-well	X		X		X
Cistern	X	X	X		X
Foundation planting	X	X			X
Pop-up drainage emitters		X			
Landscape					
Grass/vegetated swales	X	X		X	X
Extended detention (dry) ponds	X		X	X	X
Wet ponds	X		X	X	X
Bio-retention areas	X		X	X	X

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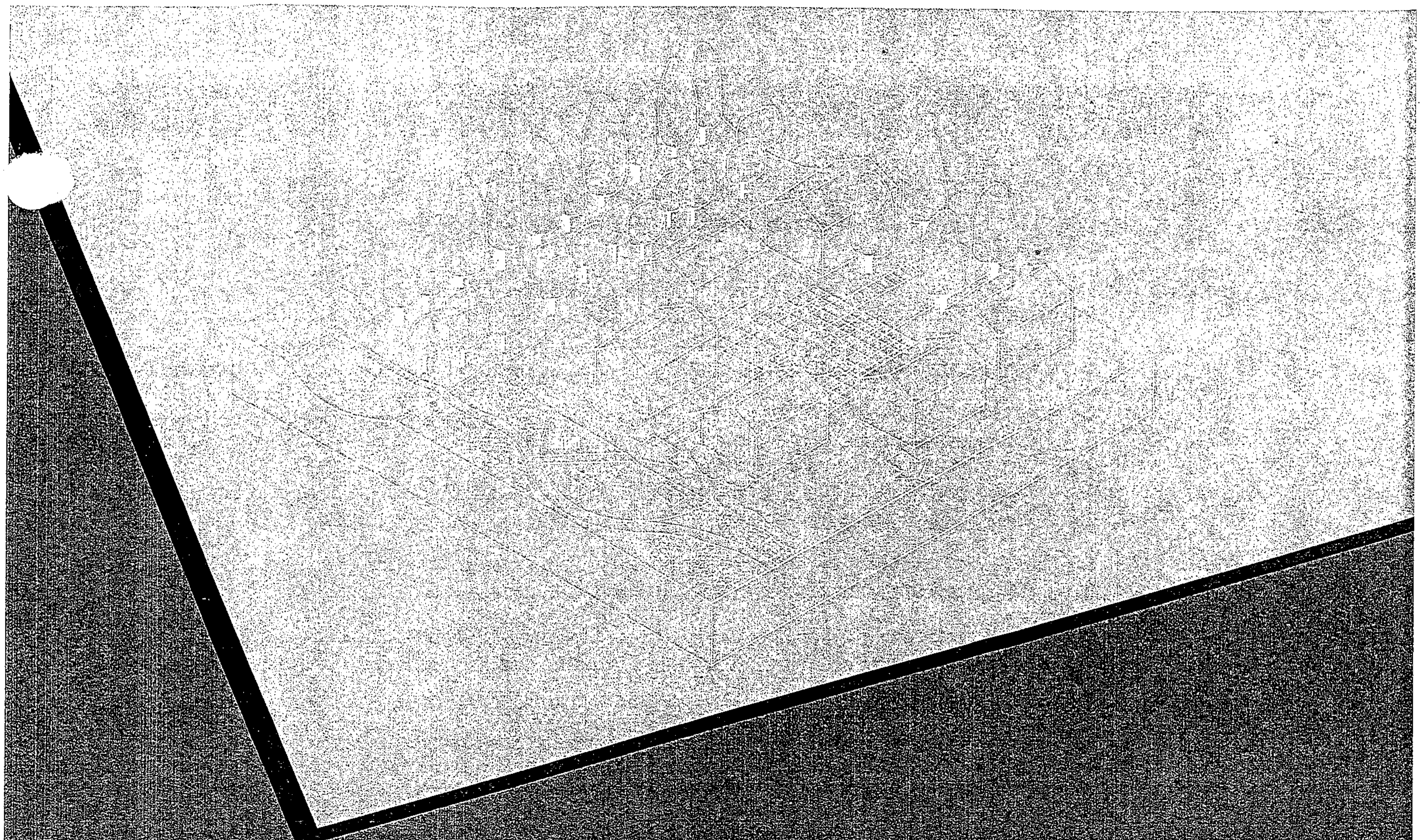

Using Site Design Techniques to Meet Development Standards for Stormwater Quality

A Companion Document to Start at the Source

May 2003

Bay Area Stormwater Management Agencies Association

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Using Site Design Techniques to Meet Development Standards for Stormwater Quality

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1 Introduction

1.1 Start at the Source Approach

To address stormwater quality during the planning and design phase of new development and redevelopment projects, the Bay Area Stormwater Management Agencies Association (BASMAA) developed *Start at the Source – Residential Site Planning and Design Guidance Manual for Stormwater Quality Protection* (BASMAA, 1997). This first edition introduced design concepts that could reduce the impact of new development and redevelopment on water quality by addressing pollutants at their source. The manual focused on implementation of Best Management Practices (BMPs) for complying with *qualitative* land development requirements contained within first and second generation NPDES stormwater permits. In 1999, BASMAA prepared a second edition titled *Start at the Source – Design Guidance Manual for Stormwater Quality Protection.* This second edition expanded on the first edition in two ways – by covering industrial/commercial and institutional development, and by providing more detailed technical information.

Recent stormwater permits have evolved to include more specific *quantitative* requirements regarding development and redevelopment. This document demonstrates ways to utilize the techniques described in BASMAA's second edition of *Start at the Source* to help comply with these quantitative permit requirements.

The development and redevelopment planning process involves not only planning, engineering, and landscape architect professionals, but also staff and elected and appointed officials from cities, counties, and local agencies. To address stormwater quality issues during the process, the *Start at the Source* approach aims to convey basic stormwater management concepts that can be adapted to site and project specific conditions.

Development and redevelopment projects that incorporate site design techniques such as detention, retention, and infiltration of runoff, like concave medians, permeable pavements, and conservation of natural areas, exhibit reduced runoff volumes and rates when compared to projects of similar magnitude where the techniques are not utilized. The runoff volume and rate reductions achieved with site design techniques translate directly to reductions in the amount of runoff that must be treated to comply with permit requirements and managed to protect streams from erosion. See Figure 1-1.

1.2 More Information

This manual does not provide detailed information on how to select or size specific site design techniques or other stormwater treatment measures. Sources for stormwater quality design information to supplement this manual include:

- California Stormwater Best Management Practice Handbooks (California Stormwater Quality Association, 2003)
- Urban Runoff Quality Management, WEF Manual of Practice No. 23, ASCE Manual and Report on Engineering Practice No. 87, 1998

These sources will help you complete the design calculations discussed in this document.

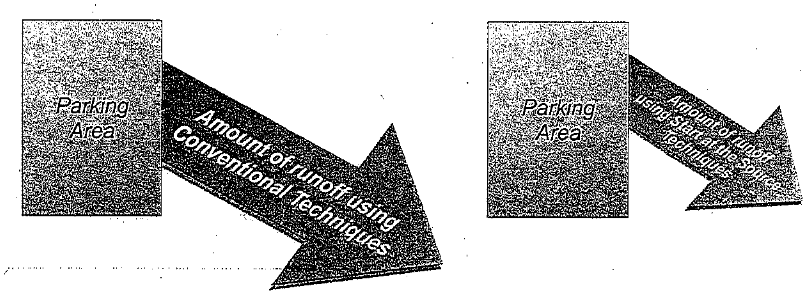

Figure 1-1
***Start at the Source* Reduces Post Development Runoff Volumes**

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2 Current Land Development Requirements

2.1 Overview of General Requirements

Recently issued municipal stormwater discharge permits now contain quantitative requirements regarding stormwater controls for new development and redevelopment. Most new development and redevelopment projects must now treat runoff prior to being discharged to storm drains. The requirements set forth minimum standards for sizing newly constructed treatment controls. Sizing standards are prescribed for both:

- Volume-Based BMPs
- Flow-Based BMPs

Volume-based BMP design standards generally call for the capture and infiltration and/or treatment of the 80th to 85th percentile runoff volume. While this requirement may seem as if it calls for capturing the runoff from large, infrequent storms, in most areas it merely amounts to capturing the runoff from relatively small storms that occur several times per year. Such small storms produce more total runoff than larger more infrequent storms. See Figure 2-1. Local development requirements should be referenced for the specific percentile runoff volume that must be addressed.

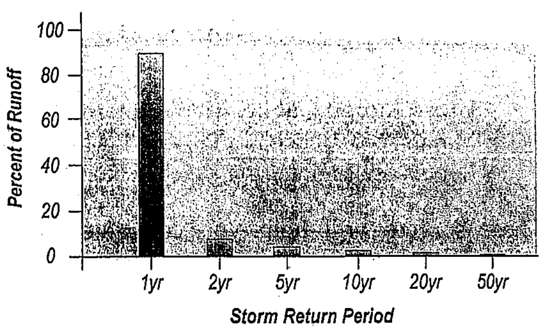

Figure 2-1
Small Storms Add Up

Flow-based BMP design standards generally call for the capture and infiltration and/or treatment of runoff flows produced by the 85th percentile hourly rainfall intensity plus a safety factor. As mentioned above, this requires treating flows from only small, frequent storm events.

Start at the Source provides many site design techniques directly applicable to meeting these land development requirements.

2.2 Volume-Based BMP Design Standards

According to current municipal permits, treatment BMPs whose primary mode of action depends on volume capacity to remove pollutants, such as retention or infiltration structures, shall be designed to treat a volume of stormwater runoff equal to:

- The maximized stormwater quality capture volume for the area, based on historical rainfall records, determined using the formula and volume capture coefficients set forth in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998), pages 175-178; <u>or</u>
- 80 percent of the volume of annual runoff, determined by using local rainfall data in accordance with methodology set forth in Appendix D of the California Stormwater Best Management Practices New Development and Redevelopment Handbook (2003). The BMP Handbooks have recently been revised.

2.3 Flow Based BMP Design Standards

Current municipal stormwater permits also require that treatment BMPs whose primary mode of action depends on flow capacity, such as swales, sand filters, or wetlands, be sized to treat:

- 10% of the 50-year design flow rate; <u>or</u>
- The flow of runoff produced by a rain event equal to at least two times the 85th percentile hourly rainfall intensity for the applicable area, based on historical records of hourly rainfall depths; <u>or</u>
- The flow of runoff resulting from a rain event equal to at least 0.2 inches per hour intensity.

2.4 Which Design Approach to Use?

Some BMPs are designed based on volume, flow, or a combination of both. The design basis is dependent upon the primary mode of action for the specific BMP. For example, the design of extended detention (dry) ponds requires a volume-based design approach, vegetated swales require a flow-based design approach, and concave medians require a combination of volume-based and flow-based design approaches. Table 3-1 lists various site design and landscape techniques and indicates whether a volume-based approach, flow-based approach, or both, is appropriate for the design of each technique.

In determining which design approach to use, apply the locally approved design standards to the BMP design guidance found in the references noted in Section 1.2.

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3 Site Design for Stormwater Quality Protection

3.1 Site Design for Stormwater Quality Protection

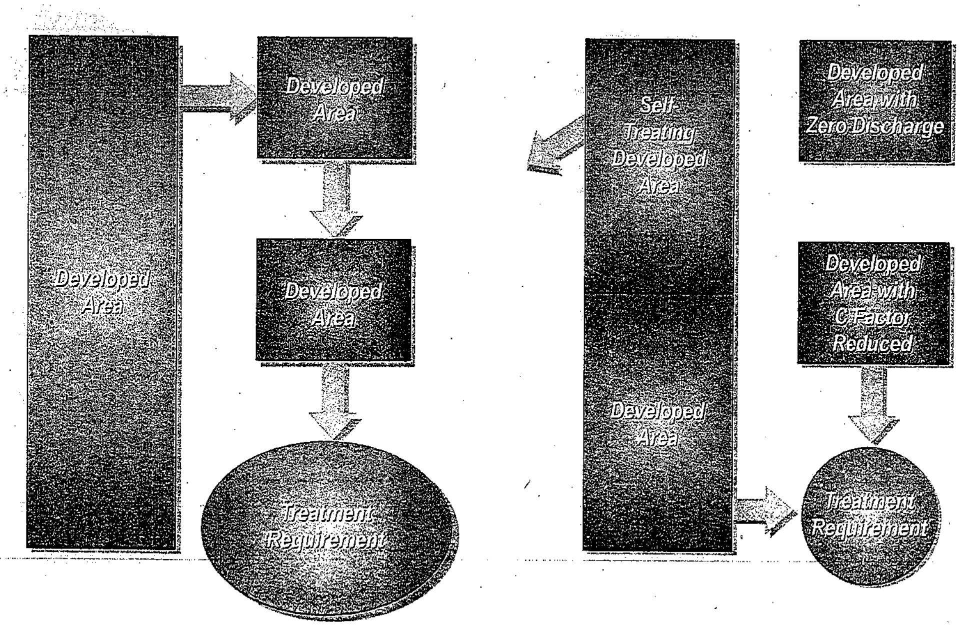
Reducing the amount of runoff required to be captured and infiltrated and/or treated may be achieved by applying the following design philosophies during the planning and design stage of development:

- **Zero Discharge Areas** – areas that have been designed to infiltrate or retain the volume of runoff requiring treatment
- **Self-Treating Areas** – areas that have been designed to provide "self-treatment" without additional BMPs
- **Runoff Reduction Areas** – areas that have been designed using alternative materials or surfaces that may reduce the volume of runoff

Figure 3-1 conceptually illustrates how these philosophies may be used to reduce treatment requirements during development and redevelopment. The design philosophies are explained in detail in the following sections.

The site design techniques do not require radical changes in design methods or development planning. The techniques may simply be incorporated into the standard features of a development, requiring only small changes or refinements in design. For example, an area reserved to meet landscaping requirements can also be used to meet stormwater treatment requirements. The key is to incorporate these changes early on in the planning and design process. Appropriately applied, these techniques can reduce runoff volume and flow rate, which reduces the infrastructure necessary to treat and convey stormwater.

Table 3-1 presents a list of site design and landscaping techniques and indicates whether they are applicable for use in Zero Discharge Areas, Self-Treating Areas, and Runoff Reduction Areas. Several different techniques may be implemented within the same design philosophy. Some techniques may be used to implement more than one design philosophy. Where feasible, combinations of multiple techniques may be incorporated into new development and redevelopment projects to minimize the amount of treatment required.



Conventional Design Approach — *Start at the Source* Design Approach

Figure 3-1
Reducing the Size of Treatment Requirements

Table 3-1
Site Design and Landscaping Techniques

	Design Criteria		Design Philosophy [1,2]		
Site Design and Landscape Techniques	**Volume-Based Design**	**Flow-Based Design**	**Zero Discharge**	**Self – Treating**	**Runoff Reduction**
Permeable pavements					
Pervious concrete	X				X
Pervious asphalt	X				X
Turf block	X			X	X
Un-grouted brick [3]	X				X
Un-grouted natural stone [3]	X				X
Un-grouted concrete unit pavers [3]	X				X
Unit pavers on sand	X				X
Crushed aggregate	X				X
Cobbles	X				X
Wood mulch	X				X
Streets					
Urban curb/swale system	X	X			X
Rural swale system	X	X			X
Dual drainage systems	X	X			X
Concave median	X	X	X	X	X
Pervious island	X	X		X	X
Parking lots [4]					
Hybrid surface parking lot	X				X
Pervious parking grove	X				X
Pervious overflow parking	X			X	X
Driveways [4]					
Not directly connected impervious driveway		X			X
Paving only under wheels	X			X	X
Flared driveways	X				X
Buildings					
Dry-well	X		X	X	X
Cistern	X	X	X	X	X
Foundation planting	X	X			X
Pop-up drainage emitters		X			X
Blue roofs [5]	X		X	X	X
Green roofs [5]	X		X	X	X
Landscape					
Grass/vegetated swales	X	X		X	X
Extended detention (dry) ponds	X		X	X	X
Wet ponds	X		X	X	X
Bio-retention areas	X		X	X	X
Fountains	X		X		

Notes:
(1) The above site design and landscape techniques may be applicable to more than one design philosophy; for example, turf block may be used as part of a self-treating area or runoff reduction area.
(2) These techniques must be designed and located properly to achieve the desired treatment requirement reduction.
(3) The open area between brick, stone, and pavers design techniques is critical, as the spaces provide perviousness.
(4) Options for parking lot and driveway surface treatments are covered under permeable pavements. See Start at the Source for details.
(5) Green roofs are vegetative, landscaped rooftops. Blue roofs are rooftops designed to detain or retain stormwater.

4 Zero Discharge Areas

4.1 Design Philosophy

An area within a development or redevelopment project can be designed to infiltrate or retain the volume of runoff requiring treatment from that area.

The term "zero discharge" in this philosophy applies at stormwater treatment design storm volumes. For example, consider an area that functionally captures and then infiltrates the 80th percentile storm volume. If permits require treatment of the 80th percentile storm volume, the area generates no *treatment-required* runoff.

Site design techniques available for designing areas that produce no treatment-required runoff include:

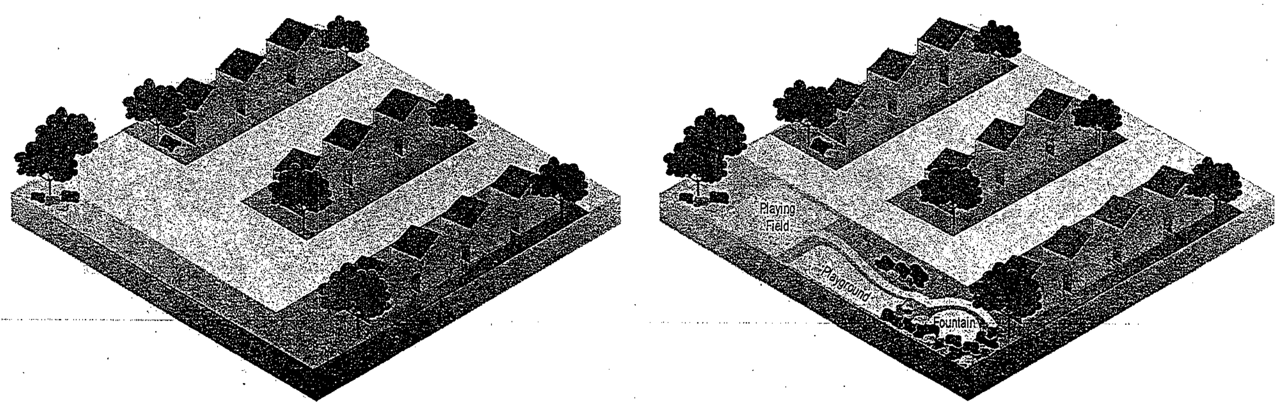
- Retention Ponds
- Wet Ponds
- Infiltration Areas
- Large Fountains
- Retention Rooftops
- Green and/or Blue Roofs

Infiltration areas, ponds, fountains, and green/blue roofs can provide "dual use" functionality as stormwater retention measures and development amenities. Retention ponds and infiltration areas can double as playing fields or parks. Wet ponds and infiltration areas can serve dual roles when meeting landscaping requirements.

When several "zero discharge" areas are incorporated into a development design, significant reductions in volumes requiring treatment may be realized.

"Zero discharge" areas such as wet ponds, retention ponds, and infiltration areas can be designed to provide treatment over and above the storm volume captured and infiltrated. For example, after a wet pond area has captured its required storm volume, additional storm volume may be treated via settling prior to discharge from the pond. In this case, the "zero discharge" area converts automatically into a treatment device for runoff from other areas, providing settling for storm volumes beyond treatment requirements. Another example is a grassy infiltration area that converts into a treatment swale after infiltrating its area-required treatment volume. The grassy infiltration area in this example becomes a treatment swale for another area within the development.

Figure 4-1 illustrates a residential tract, and a tract incorporating Zero Discharge Area techniques (infiltration areas). The Zero Discharge Area designed tract represents a design to infiltrate (i.e., achieve zero discharge from) a portion of the tract's runoff, reducing total runoff from the tract.



Conventional Design Approach

Start at the Source Design Approach

Figure 4-1
Zero Discharge Area Usage

4.2 Zero Discharge Area Example

The following example problem compares sizing a retention basin using conventional design methods, to sizing the basin using *Start at the Source* design techniques. Figure 4-2 represents a conventionally designed residential tract with a retention basin.

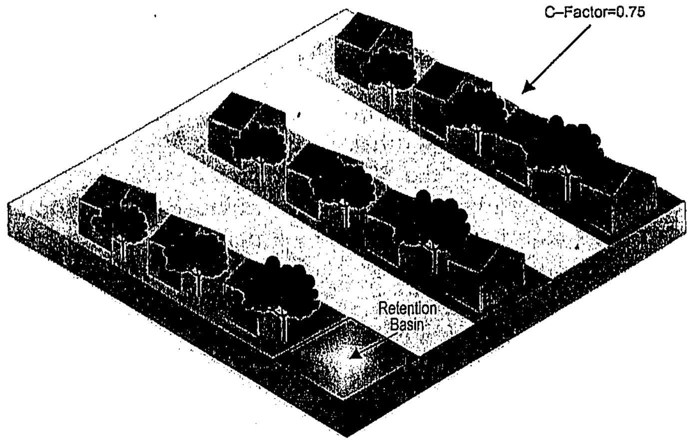


Figure 4-2
Conventional Design

Conventionally Designed Residential Tract:
Assume a 10-acre residential tract has a coefficient of runoff (C-Factor) of C=0.75

Start at the Source Designed Residential Tract:

- Redesign the 10-acre residential tract using the Zero Discharge Area *Start at the Source* technique. Figure 43 represents the residential tract with a 2-acre Zero Discharge Area incorporated into the development. To accommodate the Zero Discharge Area, the residential units were constructed at a higher density, resulting in a C-factor increase in the remaining 8-acre portion of the tract. Assume the redesign is comprised of:

- 2-acre portion with Zero Discharge Areas (fountains, playgrounds, wetlands, parks) with a runoff coefficient of C = 0.00

- 8-acre portion with a runoff coefficient of C = 0.85

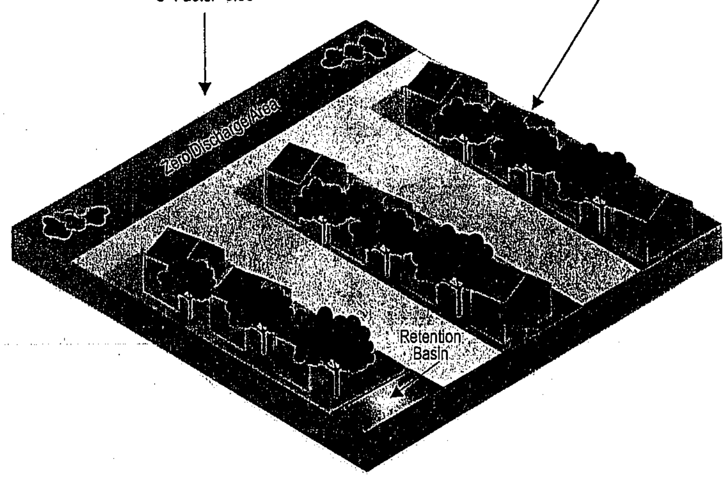


Figure 4-3
Start at the Source Design Approach

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Calculating Retention Basin Size – Conventional Design:
Using Figure 4-4, San Jose Capture Curve developed using techniques set forth in the California Storm Water BMP Handbooks (CDM, et al. 2003):

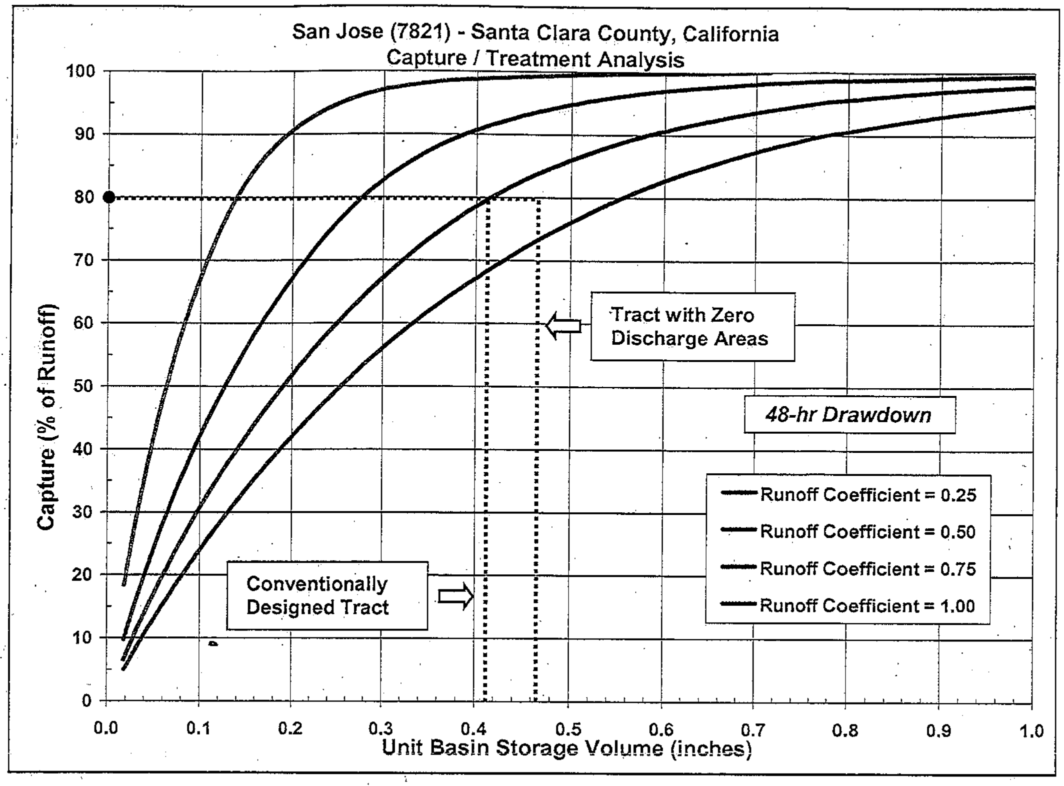


Figure 4-4
San Jose Capture Curve (California Stormwater BMP Handbooks)

By choosing the curve corresponding to a runoff coefficient of C=0.75, the Unit Basin Storage Volume is determined to be 0.41 inches, at the 80th percentile capture. Calculate the capacity of the retention basin required to treat runoff from the 10-acre residential tract:

Volume: $\forall_{Basin}$ = 10 acres × 0.41 inches = 4.10 acre -inches

Calculating Retention Basin Size – *Start at the Source* Design:
Using Figure 4-4 San Jose Capture Curve, by interpolation, the appropriate curve corresponding to a runoff coefficient of C = 0.85, would lie between the C=0.75 curve and the C=1.0 curve. For the 80th percentile capture, the Unit Basin Storage Volume is 0.46 inches.

Though use of the *Start at the Source* design technique has increased the required Unit Basin Storage Volume from 0.41 inches to 0.46 inches, the technique has reduced the total acreage of the residential tract that will produce treatment-required runoff from 10 acres to 8 acres.

Calculate the capacity of the retention basin required to treat runoff from the 8-acre portion of the tract (2-acres has zero treatment-required runoff).

Volume: $\forall_{Basin}$ = 8 acres × 0.46 inches = 3.68 acre -inches

By designing the 10-acre residential parcel using the *Start at the Source* design approach, a **10.2% reduction in treatment requirement** can be achieved.

5 Self-Treating Areas

5.1 Design Philosophy

Developed areas may provide "self-treatment" of runoff if properly designed and drained.

Self-treating site design techniques include:

- Conserved Natural Spaces
- Large Landscaped Areas (including parks and lawns)
- Grass/Vegetated Swales
- Turf Block Paving Areas

The infiltration and bio-treatment inherent to such areas provides the treatment control necessary. These areas therefore act as their own BMP, and no additional BMPs to treat runoff should be required.

As illustrated in Figure 5-1, site drainage designs must direct runoff from self-treating areas away from other areas of the site that require treatment of runoff. Otherwise, the volume from the self-treating area will only add to the volume requiring treatment from the impervious area.

Likewise under this philosophy, self-treating areas receiving runoff from treatment-required areas would no longer be considered self-treating, but rather would be considered as the BMP in place to treat that runoff. These areas could remain as self-treating, or partially self-treating areas, if adequately sized to handle the excess runoff addition.

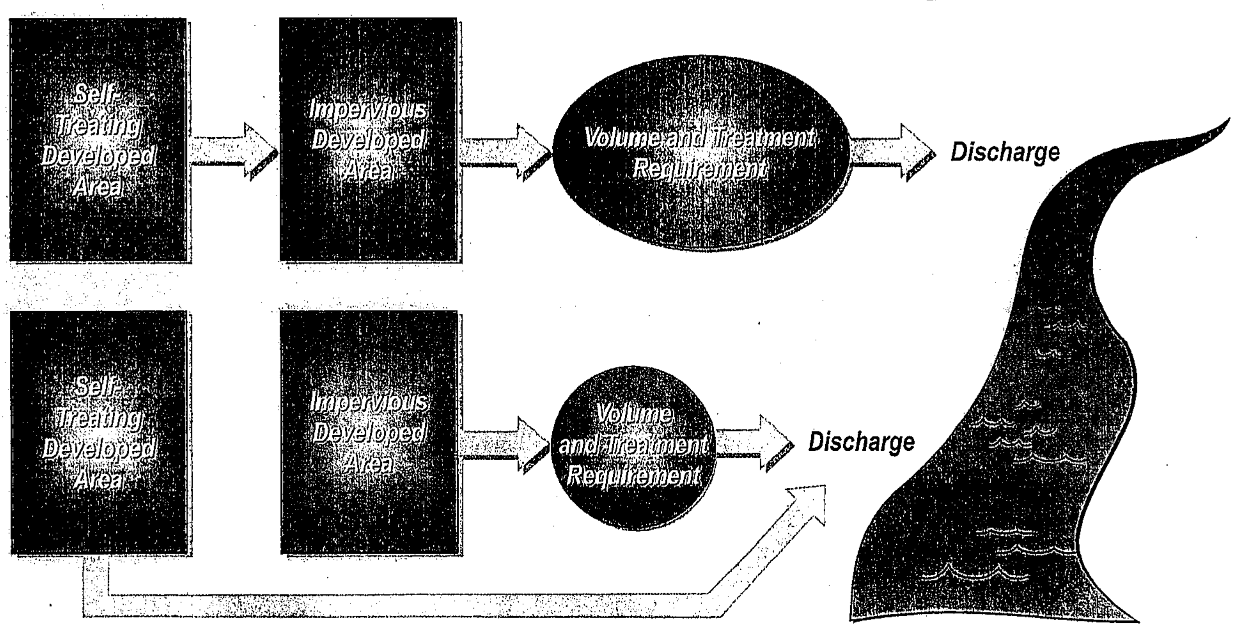
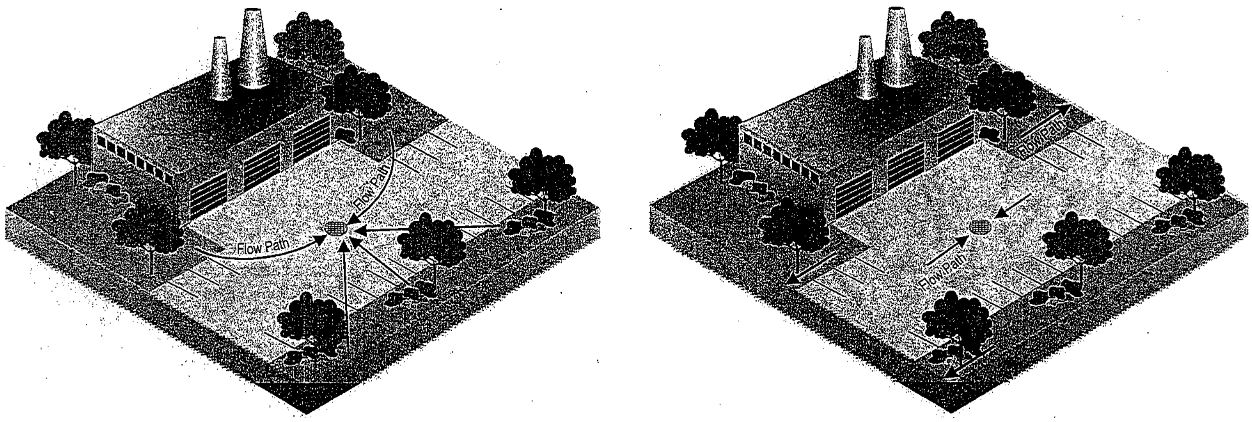


Figure 5-1
Self-Treating Area Usage

5.2 Self-Treating Area Example

The following example problem compares sizing a retention basin using conventional design methods, to sizing the basin using *Start at the Source* design techniques. Figure 5-2 represents a conventionally designed commercial/industrial lot and a commercial/industrial lot designed using the Self-Treating Area *Start at the Source* design approach. Assume the example lot is one of many similar lots making up a 100-acre commercial industrial site.



Conventional Design Approach **Start at the Source Design Approach**

Figure 5-2
Commercial/Industrial Site vs. Commercial/Industrial Site with Self-Treating Areas

Conventionally Designed Commercial/Industrial Site:
Assume a 100-acre commercial/industrial area comprised of:

- 80 acres with a runoff coefficient of 0.95 (roofs, parking lots, etc.)
- 20 acres with a runoff coefficient of 0.50 (landscape areas)

$$C_{combined} = \frac{(80\ \text{acres} \times 0.95) + (20\ \text{acres} \times 0.50)}{100\ \text{acres}} = 0.86$$

Commercial/Industrial Site Using *Start at the Source* Techniques (Self-Treating Areas):
100-acre commercial/industrial area comprised of:

- 80 acres with a runoff coefficient of 0.95 (roofs, parking lots, etc.)
- 20 acres of self-treating areas (landscape buffers, grassy areas, etc.) Note: These 20-acres do not drain to the retention basin as they are self treating. All runoff draining to the retention basin is from roofs, parking lots, etc.

Calculating Retention Basin Size – Conventional Design:
Using Figure 5-3, San Jose Capture Curve developed using techniques set forth in the California Storm Water BMP Handbooks (CDM, et al. 2003):

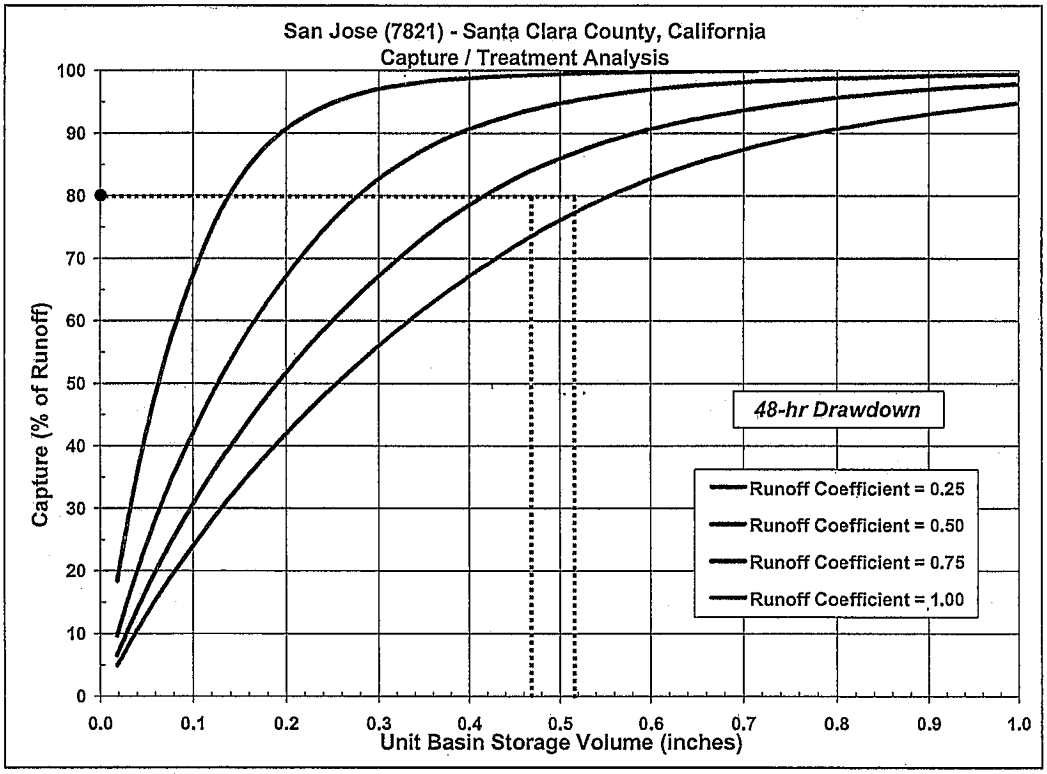


Figure 5-3
San Jose Capture Curve (California Stormwater BMP Handbooks)

By interpolation, the appropriate curve corresponding to a runoff coefficient of C combined = 0.86, would lie between the C=1.0 curve and the C=0.75 curve. For the 80th percentile runoff capture, the Unit Basin Storage Volume is 0.47 inches.

The capacity of the retention basin required to treat runoff from the 100-acre commercial/industrial area is calculated as follows:

$$\forall_{Basin} = 100 \text{ acres} \times 0.47 \text{ inches} = 47 \text{ acre-inches}$$

Calculating Retention Basin Size – *Start at the Source* Design:
Using Figure 5-3, San Jose Capture Curve:

By interpolation, the appropriate curve corresponding to a runoff coefficient of 0.95, would lie between the C=1.0 curve and the C=0.75 curve. For the 80th percentile runoff capture, the Unit Basin Storage Volume is 0.52 inches.

The capacity of the retention basin required to treat runoff from the 80-acre commercial/industrial area (excludes the 20-acres of self-treating areas) is calculated as follows:

$$\forall_{Basin} = 80 \text{ acres} \times 0.52 \text{ inches} = 41.6 \text{ acre-inches}$$

By designing the 100-acre commercial/industrial area using the *Start at the Source* design approach, an **11.5% reduction in treatment requirement** can be achieved.

6 Runoff Reduction Areas

6.1 Design Philosophy

Using alternative surfaces with a lower coefficient of runoff or "C-Factor" helps reduce runoff from developed areas. The C-Factor is a representation of a surface's ability to produce runoff. Surfaces that produce higher volumes of runoff are represented by higher C-Factors, such as impervious surfaces. Surfaces that produce smaller volumes of runoff are represented by lower C-Factors, such as more pervious surfaces. See Table 6-1 for typical C-Factor values for various surfaces during small storms.

Table 6-2 compares the C-Factors of conventional paving surfaces to alternative, lower C-Factor paving surfaces. By incorporating more pervious, lower C-Factor surfaces into a development, lower volumes of runoff are produced. Lower volumes and rates of runoff translate directly to lower treatment requirements.

Site design techniques may be used to reduce the C-Factor of a developed area, reducing the amount of runoff requiring treatment, including:

- Pervious Concrete
- Pervious Asphalt
- Turf Block
- Brick (un-grouted)
- Natural Stone
- Concrete Unit Pavers
- Crushed Aggregate
- Cobbles
- Wood Mulch

Other site design techniques such as disconnecting impervious areas, preservation of natural areas, and designing concave medians may be used to reduce the overall C-Factor of development areas.

Table 6-1
Estimated C-Factors for Various Surfaces During Small Storms

Paving Surface	*C-Factor*
Concrete	0.80
Asphalt	0.70
Pervious Concrete	0.60
Cobbles	0.60
Pervious Asphalt	0.55
Natural Stone without Grout	0.25
Turf Block	0.15
Brick without Grout	0.13
Unit Pavers on Sand	0.10
Crushed Aggregate	0.10
Grass	0.10
Grass Over Porous Plastic	0.05
Gravel Over Porous Plastic	0.05

Note: C-Factors for frequent small storms used to size water quality BMPs are likely to differ (be lower) than C-Factors developed for infrequent, large storms used to size flood control facilities. The above C-Factors were produced by selecting the lower end of the best available C-Factor range for each paving surface. These C-Factors are only appropriate for small storm treatment design, and should not be used for flood control sizing. Where available, locally developed small storm C-Factors for various surfaces should be utilized.

Table 6-2
Conventional Paving Surface Small Storm C-Factors vs. Alternative Paving C-Factors

Conventional Paving Surface C-Factors	*Reduced C-Factor Paving Alternatives*
Asphalt Parking Area (0.70)	Crushed Aggregate (0.10)
Concrete Patio/Plaza (0.80)	Decorative Unit Pavers on Sand (0.10)
	Turf Block Overflow Parking Area (0.15)
	Pervious Asphalt (0.55)
	Pervious Concrete (0.60)

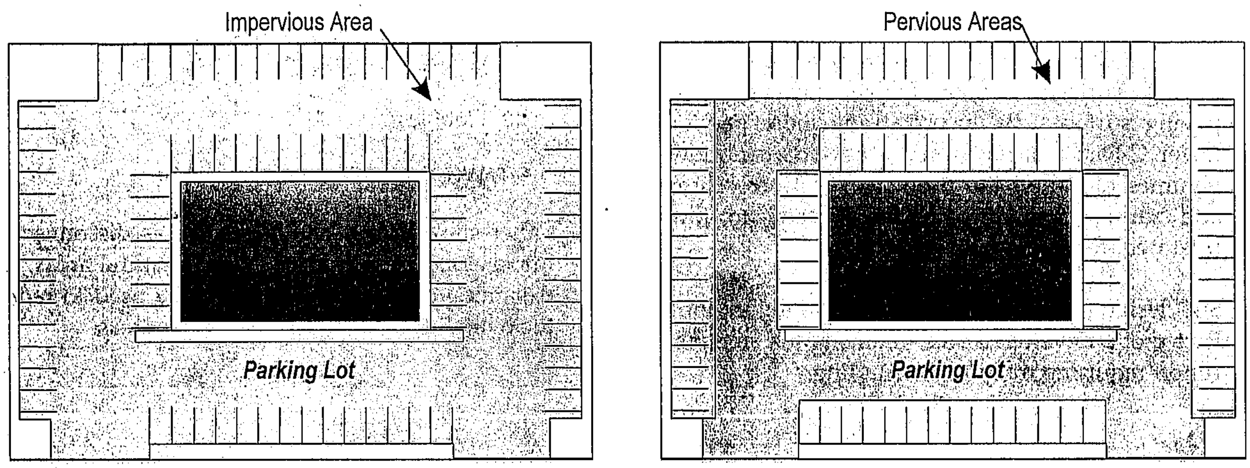


Figure 6-1
Impervious Parking Lot vs. Parking Lot with Some Pervious Surfaces

6.2 Runoff Reduction Area Example

The following example problem compares sizing a treatment swale using conventional design methods, to sizing the swale using *Start at the Source* design techniques.

Conventionally Designed Paved Parking Lot:
1-acre parking lot with a C-Factor of 0.80

Paved Parking Lot Using *Start at the Source* Techniques (Porous Pavement – See Figure 6-2):
1-acre parking lot with a C-Factor of 0.60

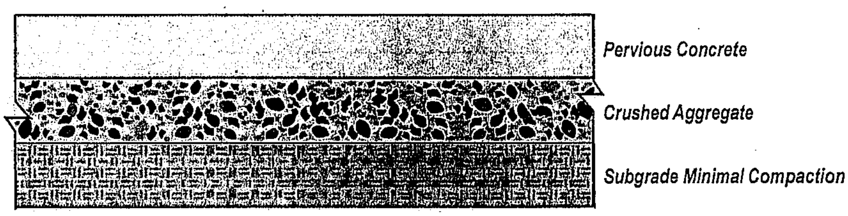


Figure 6-2
Porous Pavement

Calculating Swale Size:
Using the Urban Runoff Quality Management ASCE/WEF Manual guidelines for Selection and Design of Passive Treatment Controls:

Step 1: Determine Runoff
Using the Rational Method Q = CIA to solve for Q, given a rainfall intensity of 0.2 inches/hour

Where Q = Flow (cubic feet/second, cfs)

C = Runoff Coefficient

I = Rainfall Intensity (inch/hour)

A = Total Site Area (acres)

Calculating Runoff – Conventional Design:

Q = CIA
= 0.80 × 0.2 inches/hour × 1 acre
= 0.16 cubic feet/second

Calculating Runoff – *Start at the Source* Design:

Q = CIA
= 0.60 × 0.2 inches/hour × 1 acre
= 0.12 cubic feet/second

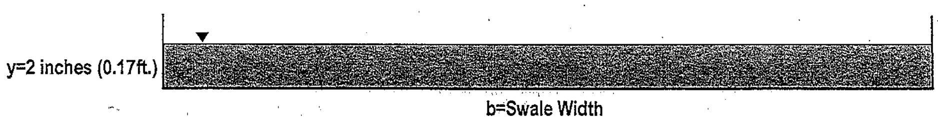
Step 2: Determine swale slope
Assume 1% or 0.01

Step 3: Select vegetation cover
Assume grass-lined swale

Step 4: Determine vegetation height
Assume 2 inches or 0.17 feet

Step 5: Select Manning's n value
Manning's n = 0.20, for routinely mowed grass-lined channels

Step 6: Select cross-sectional shape of swale
A typical swale cross-section is parabolic or trapezoidal in shape. The 2-inch (0.17 ft) flow depth in this example allows a rectangular cross-sectional approximation.



Step 7 Use Manning's equation to determine swale width
Manning's equation: $Q = 1.49/n \times R^{2/3} \times S^{1/2} \times A$

Where Q = Flow

n = Manning's n

R = Hydraulic Radius = A / (b + 2y) for rectangular channels

S = Slope of swale

A = Cross-sectional Area = b × y for rectangular channels

y = Flow Depth = Vegetation Height for Treatment Swale

b = Swale Width

Using Manning's equation to solve for Swale Width, b:

Swale Width = 4.3 feet (Conventional Design)

Swale Width = 3.3 feet (*Start at the Source* Design)

Step 8: Determine flow velocity

Flow Velocity – Conventional Design:

Velocity = Runoff / Cross-sectional Area
= Q / A
= 0.16 cfs / (0.17 feet × 4.3 feet)
= 0.22 feet/second

Flow Velocity – *Start at the Source* Design:

Velocity = Runoff / Cross-sectional Area
= Q / A
= 0.12 cfs / (0.17 feet × 3.3 feet)
= 0.21 feet/second

Step 9: Determine swale length

Using Urban Runoff Quality Management Manual guidelines (p195), assume swale detention time of 7 minutes = 420 seconds

Swale Length – Conventional Design:

Length = Velocity × Detention Time
= 0.22 feet/second × 420 seconds
= 92.4 feet

Swale Length – *Start at the Source* Design:

Length = Velocity × Detention Time
= 0.21 feet/second × 420 seconds
= 88.2 feet

Step 10: Determine swale size (surface area)

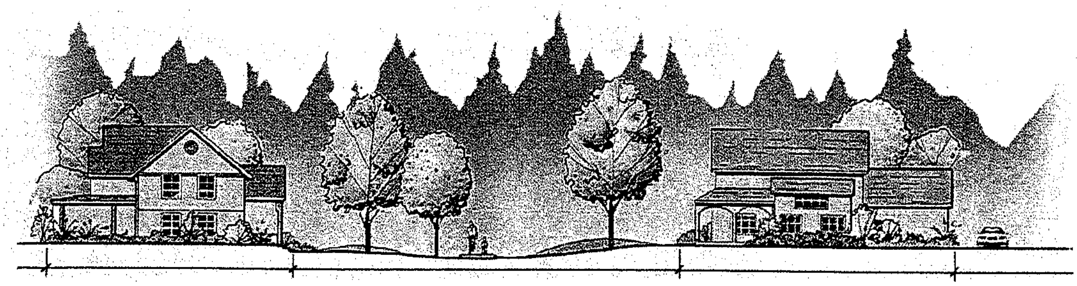
Swale Size – Conventional Design:

Swale Size = Swale Length × Swale Width
= 92.4 feet × 4.3 feet
= 397 square feet

Swale Size – *Start at the Source* Design:

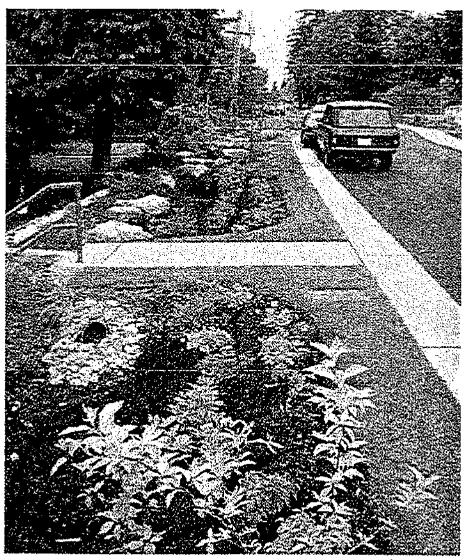
Swale Size = Swale Length × Swale Width
= 88.2 feet × 3.3 feet
= 291 square feet

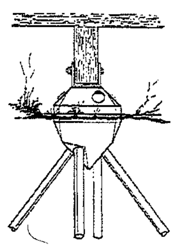
By designing the parking lot using the *Start at the Source* design approach, a **27% reduction in treatment requirement** can be achieved.

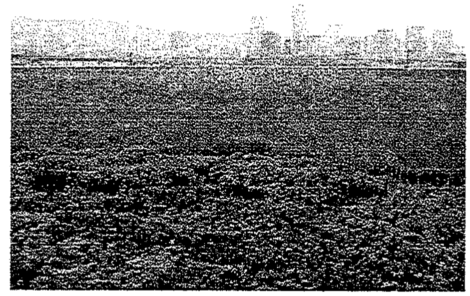


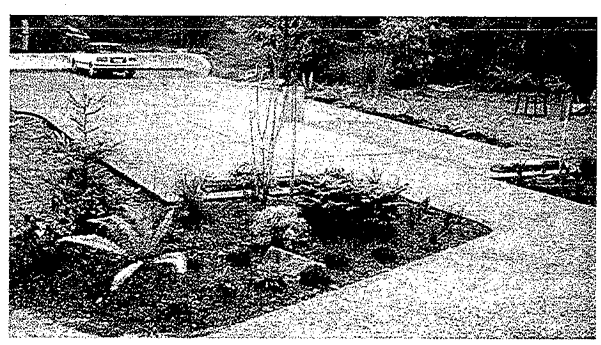
LOW IMPACT DEVELOPMENT

TECHNICAL GUIDANCE MANUAL FOR PUGET SOUND









JANUARY 2005

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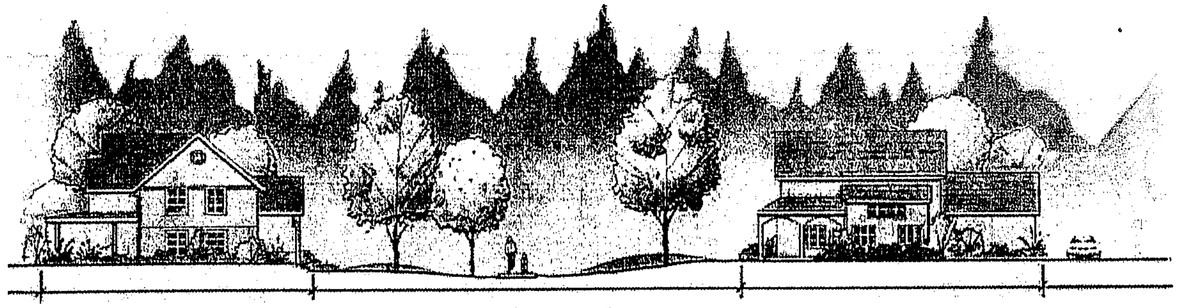

LOW IMPACT DEVELOPMENT

TECHNICAL GUIDANCE MANUAL FOR PUGET SOUND

JANUARY 2005
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Permeable concrete walkway and parking area, Whidbey Island *(Greg McKinnon).*
Permeable paver detail *(Gary Anderson).*
Bioretention swale, Seattle *(Seattle Public Utilities).*
PIN pier section *(Rick Gagliano).*

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Table of Contents

Preface

Low impact development (LID) is a stormwater management strategy that emphasizes conservation and use of existing natural site features integrated with distributed, small-scale stormwater controls to more closely mimic natural hydrologic patterns in residential, commercial, and industrial settings.

Many of the tools used for LID are not new. Village Homes in Davis, California, constructed in the early 1970s, is perhaps the earliest recognized example of a residential subdivision that manages stormwater through open conveyance systems and provides storm flow retention in open space integrated throughout the development. During the early 1980's European cities began using distributed, integrated stormwater management practices to reduce flows from combined sewer systems. In the late 1980's, Larry Coffman with the Department of Environmental Resources in Prince George's County, Maryland began working on a plant, soil-microbe filter designed to mimic natural forest hydrologic characteristics (bioretention, or rain gardens). Today LID strategies are an integral part of Prince George's County's stormwater management approach and numerous developments across the U.S., Canada, and Europe include LID practices.

In Puget Sound, state and local government agencies and university extension programs have offered and continue to offer numerous workshops, conferences, and courses for engineers, planners, architects, and elected officials. These focus on the problems associated with stormwater runoff, the limitations of conventional management practices, and the LID approach to protect ground and surface waters. As a result of these efforts, several local governments and state agencies are incorporating LID techniques into their stormwater manuals, development regulations, and regional guidance. Many of the organizations are using LID techniques in commercial, residential, and municipal projects. The most active of these organizations include: the cities of Seattle, Olympia, and Bellingham; King, Snohomish, and Pierce counties; Washington departments of Ecology and Transportation; and the Puget Sound Action Team (Action Team).

Initial findings from limited monitoring in Puget Sound and other studies from the U.S., Europe, Canada, and Japan indicate that LID practices can be valuable tools to reduce the adverse effects of stormwater runoff on streams, lakes, wetlands, and Puget Sound. However, important questions remain regarding relative cost, design, maintenance, and long-term performance. To answer these questions and better understand the full potential and limitations of LID in the Puget Sound region, additional research and monitoring of individual LID techniques and pilot projects are needed.

Demonstration projects and monitoring are needed to understand the long-term performance and maintenance requirements of bioretention swales and cells, permeable paving, and other LID practices in difficult (and common) Puget Sound settings, such as native soils with low infiltration rates and higher urban densities. Pilot projects will also provide data comparing LID construction costs and market performance to conventional development and stormwater management strategies.

While uncertainties regarding LID exist, current data and the need for additional tools to manage stormwater runoff warrant initiating the next steps: (1) implement and monitor demonstration projects; (2) develop regulatory guidance for LID practices; and (3) remove local regulatory barriers that discourage use of LID strategies.

New stormwater management tools are needed to address a number of critical environmental issues facing Puget Sound. Chinook and chum salmon and bull trout are listed as threatened under the federal Endangered Species Act, and scientists have cited loss of habitat due to development and stormwater runoff as one factor that has contributed to their population declines. The Washington Department of Ecology (Ecology) estimates that about one-third of all polluted waters on the section 303(d) list are degraded because of stormwater runoff. Puget Sound is one of the best regions in the world to grow clams, oysters, and other shellfish, yet thousands of acres of shellfish growing areas are closed to harvest due to stormwater runoff and other pollutant sources. Finally, more than 70 smaller local governments in Puget Sound will soon be required to comply with a federally mandated stormwater permit under the National Pollutant Discharge Elimination System Program. Newly permitted local governments will be seeking stormwater management techniques that help them comply with permit conditions and protect surface waters in an efficient, cost-effective manner.

To better address these issues, two state offices have taken significant steps related to LID. Ecology, collaborating with local government stormwater managers and Washington State University, has completed initial guidelines for flow reduction credits when LID techniques are used in projects in western Washington. The credits, included in Ecology's 2005 *Stormwater Management Manual for Western Washington* and in Chapter 7 of this manual, will provide designers with additional tools to retain stormwater on-site and reduce the size of conventional facilities that control storm flows. The Action Team, the broad partnership to conserve and recover Puget Sound, has identified LID as a priority action for the 2001-03, 2003-05, and now the 2005-07 biennial work plans to the Washington State Legislature. This emphasis has produced a national conference, regional workshops, local technical and financial assistance, and special projects, including development of this technical guidance manual. The *Puget Sound Water Quality Management Plan*, the state and federal plan to protect and restore Puget Sound, also calls on all local governments in Puget Sound to adopt new or revise existing ordinances to allow and encourage LID techniques.

Purpose of this Manual

The purpose of this manual is to provide stormwater managers and site designers with a common understanding of LID goals, objectives, specifications for individual practices, and flow reduction credits that are applicable to the Puget Sound region.

In addition to the guidelines for specific practices, this manual provides research and data related to those practices to help managers and designers make informed decisions when adapting LID applications to their jurisdictions. Low impact development is a new and evolving management approach; accordingly, this document will evolve and be periodically updated as additional research becomes available and professionals in the region gain more practical experience. This is a technical manual and the information provided is targeted for engineers, planners, landscape architects, technical staff to policy makers, and developers.

How this Manual is Organized

Chapter one of the manual sets the context for the LID approach with an introduction to Puget Sound lowland hydrology and the effects of urban development on streams, wetlands, and Puget Sound. Chapter one also establishes the goals and objectives for LID. Chapters on site assessment, planning and layout, vegetation protection, and clearing and grading follow, and emphasize the importance of planning and protecting native vegetation and soils in the LID approach. Chapter six provides general guidance for six integrated management practices (IMPs), as well as detailed construction and material specifications for many of the IMPs. Chapter seven provides the new credits in the Western Washington Hydrology Model that will allow engineers to reduce the size of conventional flow control facilities when using LID practices. Finally, several appendices include sample specifications, lists of plants appropriate for LID applications, and tables summarizing bioretention and permeable paving research. Bolded words within the text of the manual are defined in the glossary of terms.

Low Impact Development Applications

The LID approach can be applied in a variety of settings including: large lots in rural areas; low, medium, and high-density development within urban growth boundaries; redevelopment of highly urbanized areas; and commercial and industrial development. LID applications can be designed for use on glacial outwash and alluvium soils, as well as soils with low infiltration rates, such as dense silt loams or till mantled areas.

1 Introduction

In this chapter...

- *Puget Sound hydrology*
- *Current stormwater management*
- *Impacts of urbanization*
- *Low impact development goals and objectives*

1.1 Puget Sound Hydrology

Native forests of the Puget Sound lowlands intercept, store, and slowly convey precipitation through complex pathways. Water budget studies of wet coniferous forests in western Washington, British Columbia, and the United Kingdom indicate that approximately 50 percent of the annual rainfall is intercepted by foliage and evaporated during the rainy season. Bauer and Mastin (1997) found that interception and evaporation from vegetation during the winter months (approximately 50 percent) far exceeded estimates for western Washington, and attributed the high rate to the large surface area provided by evergreen trees, relatively warm winter temperatures, and the advective evaporation of precipitation. Bidlake and Payne (2001) and Calder (1990) also found that the aerodynamically rough forest canopy and **advection energy** supported evaporation rates of intercepted precipitation that were higher than estimated radiation-based potential **evapotranspiration**.

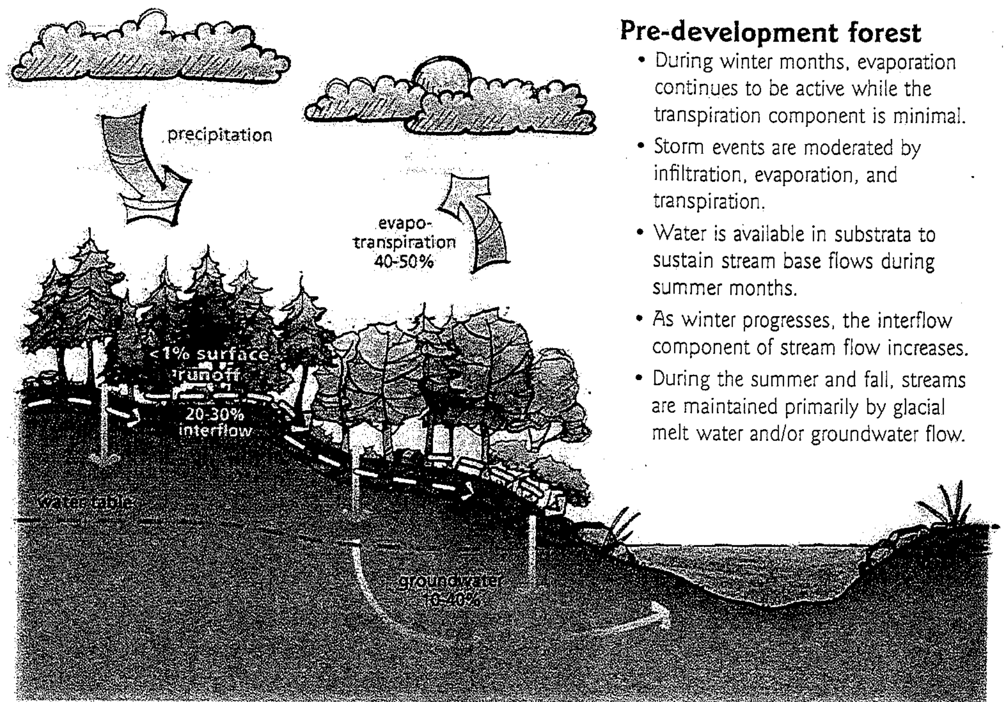
> *Water budget studies of wet coniferous forests in western Washington, British Columbia, and the United Kingdom indicate that approximately 50 percent of the annual rainfall is intercepted by foliage and evaporated during the rainy season.*

Native soils also play a critical role in storage and conveyance of Pacific Northwest (PNW) rainfall. Typically, 2 to 4 feet of soil, high in organic material and biologically active near the surface, overlays the subsurface geology. Solar radiation and air movement provide energy to evaporate surface soil moisture that contributes to the overall evapotranspiration component. Soil biota and organic matter chemically and physically bind mineral particles into stable aggregates that build soil structure, increase soil porosity, and provide 20 to 30 percent of active water storage by volume. Shallow subsurface flow (interflow) moves slowly down slope or down gradient over many hours, days or weeks through these upper soil layers. Depending on the underlying soil type and structure, 10 to 40 percent of the annual precipitation moves to deeper groundwater (Bauer and Mastin, 1997).

For most storm events, the gentle rainfall intensities are less than the combined capacity of the interception loss, and vegetation and soil storage in native Puget Sound forests; as a result, overland flow does not occur or is minimal (Booth, Hartley and Jackson, 2002). Instead, the storm flow moves downslope below the surface at a much slower rate than overland flow and displaces antecedent, subsurface water in areas near streams, lakes and wetlands (Bauer and Mastin, 1997). The displaced soil water adjacent to water bodies contributes to stream flows or wetland and lake levels rather than the entire watershed. As storms and the wet season progress, available soil storage capacity declines and the saturated or contributing areas near receiving waters increase as does the response to storm events (Booth et al., 2002).

Figure 1.1 Water budget for pre-development Puget Sound lowland forests.

Graphic by AHBL Engineering

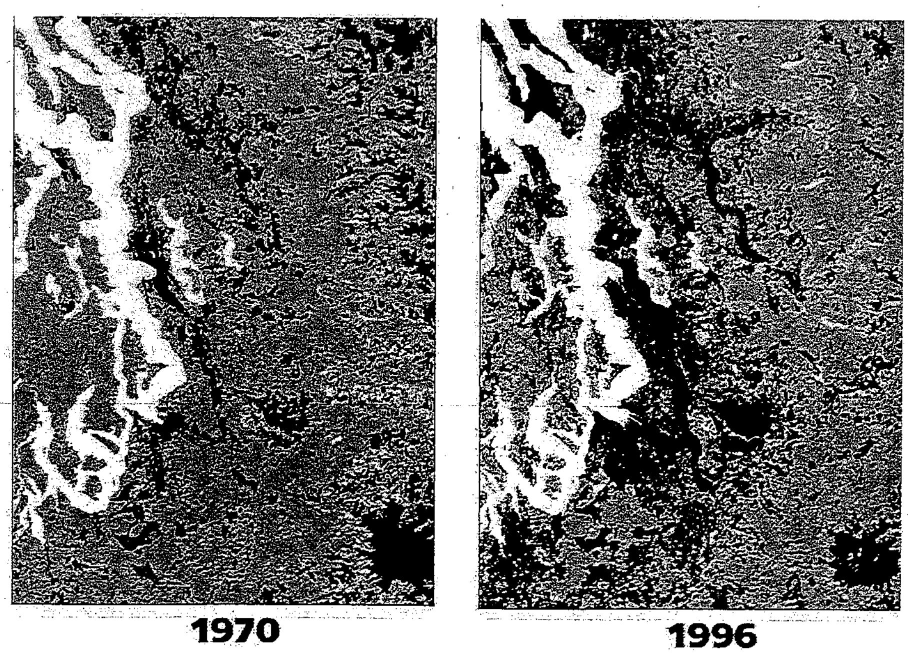


1.2 Impacts of Urbanization

The transition from a native landscape to a built environment increases the impervious surface coverage of roads, parking areas, sidewalks, rooftops, and landscaping. These changes reduce, disrupt or entirely eliminate native vegetation, upper soil layers, shallow depressions, and native drainage patterns that intercept, evaporate, store, slowly convey, and infiltrate stormwater. As development progresses, the area in small watersheds that contribute overland flow to receiving waters in minutes increases while the area that stores and delivers subsurface flow over periods of hours, days or weeks diminishes (Booth et al., 2002).

Figure 1.2 Satellite images of Puget Sound in 1970 and 1996. (Dark color in lowlands areas indicates clearing of vegetation and development.)

Source: American Forests



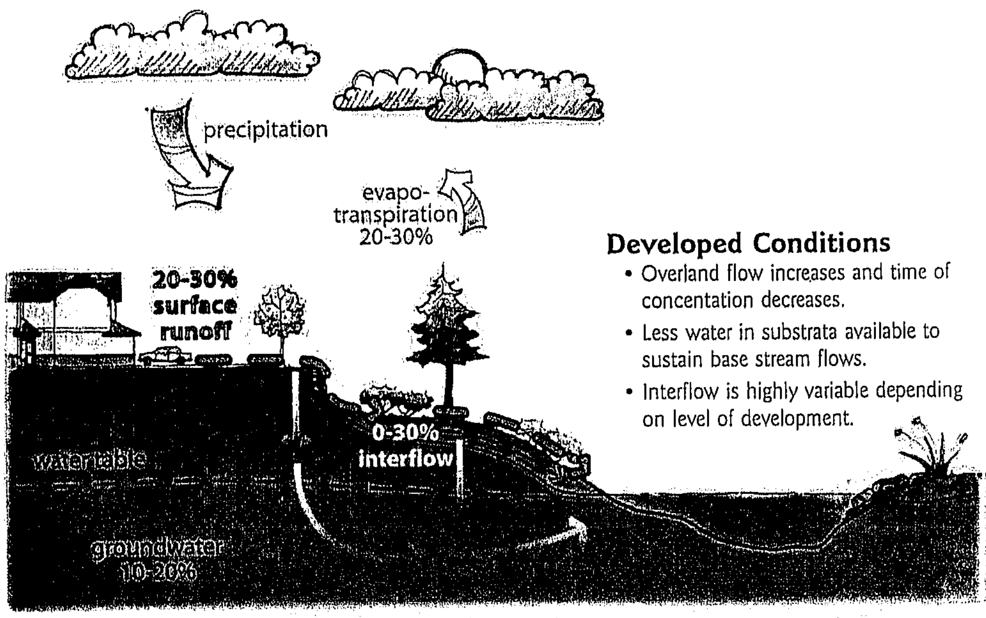


Figure 1.3 Water budget for typical suburban development in the Puget Sound lowlands.

Graphic by AHBL Engineering

Loss of native soils and vegetation within the watershed and associated changes in hydrologic regimes can significantly degrade stream habitat (Booth, 1991). **Bankful discharges**–the 1- to 1.5-year return storm flow that does much of the work to form a stream channel–increase in magnitude and frequency (Center for Watershed Protection [CWP], 2000a). Typical responses in streams exposed to high flows for longer periods of time include: excessive streambed and stream bank instability (May, Horner, Karr, Mar, and Welch, 1997); increased stream channel cross-sectional area (typically, cross sectional area is enlarged 2 to 5 times depending on the amount of total impervious area and other development factors (CWP, 2000a and March 2000); and overall loss of habitat structure, and hydraulic diversity (Booth, 1991). While water quality conditions (as defined by dissolved oxygen, temperature, sediment, various pollutant concentrations, and other parameters) are critical considerations for managing stream health, altered watershed hydrologic regimes and associated channel instability are a leading cause for in-stream physical habitat degradation and initial loss of **biotic integrity** (May et al., 1997).

> *Altered watershed hydrologic regimes and associated channel instability are a leading cause for in-stream physical habitat degradation and initial loss of biotic integrity.*

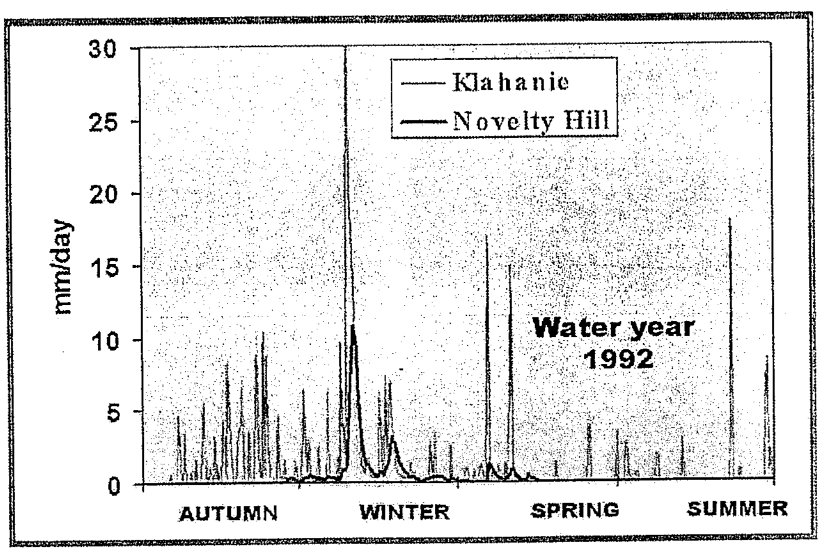


Figure 1.4 Hydrograph for an urban (Klahanie) and a rural watershed (Novelty Hill) in the Puget Sound lowlands. Storm flows increase in magnitude and frequency in the urban watershed.

Source: 'Hydrological Effects of Land-use Change in a Zero-order Catchment.' *Burges, Wigmosta and Meema, 1998.* Journal of Hydrologic Engineering. *Material reproduced with permission from the American Society of Civil Engineers.*

Figure 1.5 Down-cut stream channel resulting from increased storm flow generated by nearby development (Gig Harbor Peninsula).
Photo courtesy of Hans Hunger

Streams respond to watershed urbanization through several other important mechanisms as outlined in Table 1.1 (MacCoy and Black, 1998; May et al., 1997; Staubitz, Bortleson, Semans, Tesoriero, and Black 1997; and Washington Department of Ecology [Ecology], 1999).

Table 1.1 Degradation of watershed conditions and stream response.

Change in watershed condition	Response
Increased drainage density due to road networks, road crossings and stormwater outfalls	Increased storm flow volume and frequency, and channel erosion Increased fine sediment and urban water pollutant loads Increased fish passage barriers
Increased fine sediment deposition	Reduced intergravel dissolved oxygen levels in streambed Loss of salmonid spawning and macroinvertebrate habitat
Loss or fragmentation of riparian areas	Reduced delivery of large woody debris Reduced bank stability and loss of bank habitat structure and complexity Reduced shading and temperature control
Reduced quantity and quality of large woody debris	Reduced channel stability, sediment storage, instream cover for fish and insects, loss of pool quality and quantity
Increased pollutant loads	Synthetic organic compounds and trace elements: some acutely toxic; tumors in fish; salmon and trout will alter spawning and migration behavior in presence of metals as low as <1% of lethal concentration; **endocrine disruptors** (18 of 45 suspected endocrine disrupting trace elements found in Puget Sound fish tissue) Nutrients: excessive aquatic plant growth; excessive **diurnal oxygen fluctuations** Synergistic influence of multiple pollutants unknown

The cumulative impact of hydrologic alteration and the various other changes in watershed conditions can result in channel instability and degraded biotic integrity at low or typically rural levels of watershed development. Studies conducting empirical stream assessments observed physical degradation of channels with **effective impervious area** (EIA) percentages of less than 10 percent within the contributing watersheds (Booth et al., 2002). While impervious surface coverage generally is low at this density, forest clearing for pasture, lawns and hobby farms can be extensive across the rural landscape. Hydrologic analysis of the same watersheds (see Figure 1.6) observed the same relationship between low levels of imperviousness, changes in modeled stream flows (recurrence of pre-developed forest and developed flows), and stream channel stability. Booth, Hartley and Jackson (2002) note that observed channel instability is a relatively insensitive evaluation tool and the lack of observed degradation does not guarantee the absence of subtle, but important consequences for the physical or biologic health of streams.

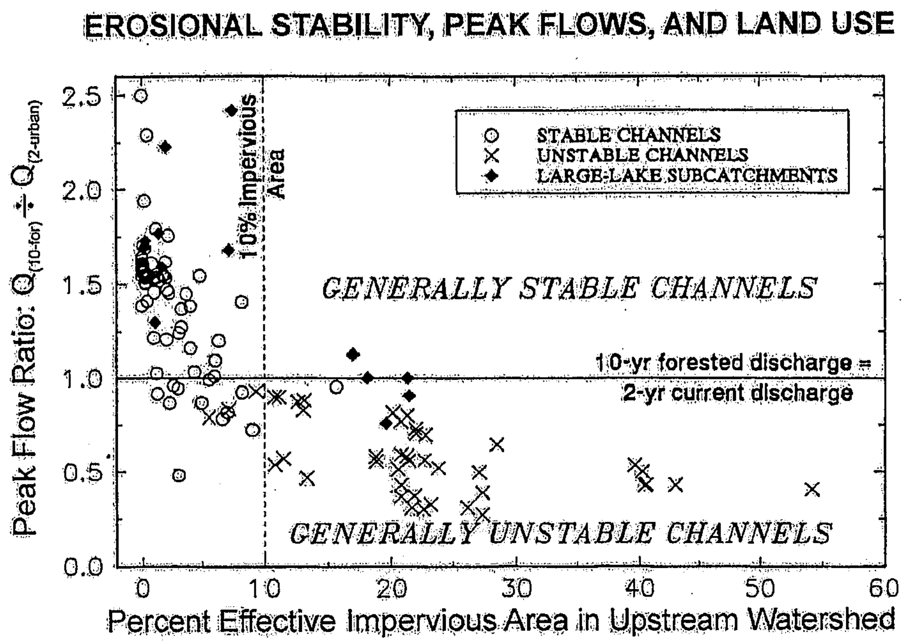


Figure 1.6 Observed stable and unstable stream channels in the Puget Sound lowlands plotted by percent EIA and ratio of modeled 10-year forested and 2-year urbanized discharges. Stable channels in this study consistently meet the apparent thresholds of EIA <10% and $Q_{(2\text{-urban})} \leq Q_{(10\text{-forest})}$ (Booth et al., 2002).

Graph courtesy of Booth and Jackson, 1997

The physical and chemical composition of wetlands and lakes are altered in response to land development as well. Typically, water levels in wetlands gradually rise in the beginning of the wet season and then subside slowly as the wet season ends. Wetland plant species have adapted to this fairly narrow and stable range of water depths and soil saturation (CWP, January 2000c). As development proceeds and impervious surfaces replace native vegetation and soils, water levels can rise rapidly in response to individual storms. A major finding in the Puget Sound Wetlands and Stormwater Management Program was that "hydrologic changes were having more immediate and measurable effects on composition of vegetation and amphibian communities than other conditions [monitored]" (Azous and Horner, 2001). Decline in wetland plant and amphibian species richness are likely when:

- Mean annual water level fluctuations exceed 20 centimeters per year.
- The frequency of **stage excursions** of 15 cm above or below pre-development condition exceeds an annual average of six.
- The duration of stage excursions of 15 cm above or below pre-development condition exceeds 72 hours per excursion.

- The total dry period (when pools dry down to the soil surface everywhere in the wetland) increases or decreases by more than two weeks in any year (Azous and Horner, 2001).
- Increased water level fluctuations occur early in the growing season (CWP, January 2000c).

Increased water level fluctuations of this nature are observed when total impervious area within the drainage area exceeds 10 to 15 percent (Taylor, 1993).

Lakes and estuaries, while not as prone to morphological change due to altered hydrology, are highly susceptible to shoreline modifications and water quality degradation from urbanization. Phosphorus, bacteria and sediment are typical urban stormwater pollutants impacting lakes. Phosphorus is often a limiting nutrient in fresh water systems, and contributes to increased plant growth and diurnal oxygen level fluctuations that degrade wildlife habitat, recreational opportunities and other beneficial uses.

Bacteria can restrict or close shellfish growing areas in Puget Sound to harvest. Nonpoint source pollution (including stormwater runoff) is now "the most common cause of shellfish classification downgrades in Puget Sound, reducing the region's commercially approved acreage by approximately 25 percent since 1980" (PSAT, 2004). Toxic pollutants associated with stormwater sediments (e.g., heavy metals and polycyclic aromatic hydrocarbons) that settle in urban estuaries and near shore areas have contributed to the listing of several urban bays as Superfund (federal) or Model Toxic Control Act (state) clean-up sites.

1.3 Current Stormwater Management

Conventional tools to manage stormwater are mitigation-based and flood-control focused. This strategy emphasizes the efficient collection and rapid conveyance of runoff from residential and commercial development to central control ponds. Several factors have led to the implementation and continuation of this approach: stormwater has been perceived as a liability and applications have evolved from wastewater technology; hard conveyance structures and central control ponds are considered reliable and relatively simple to maintain; the conveyance and collection approach is relatively simple to model for regulatory requirements; and construction costs are readily estimated.

Conventional tools to manage stormwater are mitigation-based and flood-control focused.

Newer conveyance and pond strategies, if properly designed and maintained, can match modeled pre-development peak flows and runoff rates discharged from development sites; however, a number of problems will continue to challenge current management strategies. These include:

- *Peak and volume control.* Typical residential and commercial development practice in the Puget Sound removes most, if not all, vegetation and topsoil. Suburban development in the region is estimated to have 90 percent less stormwater storage than the native forested condition, and BMP applications (circa 1994) are estimated to recover approximately 25 percent of that storage (May et al., 1997). Without infiltration, excess volume generated above the onsite storage capacity is released to receiving waters. If flows exceed **critical shear stresses,** stream channels are exposed to excessive erosion over prolonged periods (Booth et al., 2002). (See Figure 1.7 for graphic representation of actual storage needed to replace loss of native soil and vegetation.)

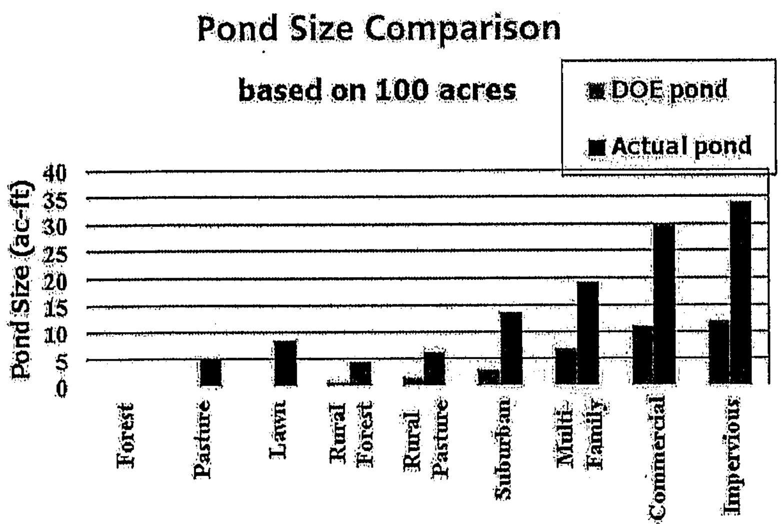


Figure 1.7 Storage required to meet Washington State Department of Ecology's stormwater management requirement (DOE Pond) and actual storage needed (actual pond) to replace loss of native soil and vegetation storage on a 100-acre site.
Source: Beyerlein, 1999.

- *Spatial Distribution.* Conventional management converts spatially distributed subsurface flows to point discharges. No analysis is currently available that focuses on the larger hydrologic impacts of this transition; however, locally severe erosion, disturbed riparian habitat, and degraded in-stream habitat can result at point discharge locations (Booth et al., 2002).
- *Density and Market Implications.* Duration-control design standards in Washington Department of Ecology's (Ecology) 2005 *Stormwater Management Manual for Western Washington* will require larger ponds. As a larger percentage of land is designated for stormwater management within the development, stormwater infrastructure costs will increase and the number of buildable lots will likely decrease.

1.4 Low Impact Development

The conventional, purely structural approach to manage stormwater runoff has limitations for recovering adequate storage and spatially distributed flow paths necessary to more closely approximate pre-development hydrologic function and protect aquatic resources from adverse effects of development. Low impact development (LID) principles and applications present a significant conceptual shift from a purely structural approach. LID is primarily a source reduction approach. Site planning and stormwater management are integrated at the initial design phases of a project to maintain a more **hydrologically functional landscape**. Hydrology and natural site features that influence water movement guide road, structure, and other infrastructure layout. Native soil and vegetation protection areas and landscaping that are strategically distributed throughout the project to slow, store, and infiltrate storm flows are designed into the project as amenities, as well as hydrologic controls.

Pre-development or natural hydrologic function is the relationship among the overland and subsurface flow, infiltration, storage, and evapotranspiration characteristics of the forested landscape predominant in the Puget Sound lowland (see Section 1.1). Low impact development strategies focus on evaporating, transpiring, and infiltrating stormwater on-site through native soils, vegetation, and bioengineering applications to reduce and treat overland flow that is characteristically negligible in the forested setting.

Low Impact Development defined

Low impact development is a stormwater management and land development strategy applied at the parcel and subdivision scale that emphasizes conservation and use of on-site natural features integrated with engineered, small-scale hydrologic controls to more closely mimic pre-development hydrologic functions.

1.4.1 The Goal of Low Impact Development

The goal of LID is to prevent measurable harm to streams, lakes, wetlands, and other natural aquatic systems from commercial, residential, or industrial development sites. The impact to receiving waters (and determining if a project has achieved the above goal) is estimated by hydrologic models and measured by monitoring surface and ground water quality and quantity, and biological health.

1.4.2 Flow Control Objective

The primary stormwater management objective for LID is to match pre-development forested hydrologic condition (or prairie condition if historic records indicate that as the native setting) over the full range of rainfall intensities and durations.

1.4.3 Flow Control Objective Discussion

Maintaining the pre-development hydrologic regime cannot be achieved everywhere or at all times given current development practices. The hydrologic system of our region evolved from, and is dependent on, the characteristics of undisturbed Pacific Northwest watersheds—mature forest canopy, uncompacted soils, ungullied hillslopes—and cannot be expected to have the same hydrologic regime when significant portions of a site are disturbed. The objectives of any given low impact development, therefore, must be strategically chosen, recognizing both the opportunities and the limitations of any given site. Regulatory requirements, typical zoning and housing types, and costs of sophisticated control technology required on sites with poor soils and higher densities, as well as site topography, soil permeability and depth, and groundwater movement create significant challenges for reducing or eliminating hydrologic impacts from development sites. These challenges are likely to be most prominent during periods of extended rainfall, where the distributed on-site infiltration reservoirs common to most LID designs will experience their highest water levels and approach, or reach, full saturation.

Initial monitoring in the Puget Sound region suggests that LID strategies can be effective for maintaining pre-development hydrologic condition for light to moderate storm events typical of a maritime climate (Horner, Lim and Burges, 2002). Effectiveness in mimicking pre-development hydrology for large storms and during extended wet periods is not well documented. On difficult sites with low infiltration rates and higher densities, additional storage using conventional retention or detention pond facilities may be necessary in concert with LID strategies. Properly designed and implemented LID applications will, however, significantly reduce pond size requirements (Derry, Butchart and Graham, 2004 and Horner et al., 2002).

Properly designed and implemented LID applications will significantly reduce the size requirements of ponds.

1.4.3.1 Rural setting

Empirical data coupled with hydrologic modeling analysis, at the watershed scale, suggest that retaining 65 percent mature forest cover is necessary to mimic pre-development hydrologic conditions and maintain stable stream channels on moderately sloping till soils and typical rural development settings (EIA 3 to 5 percent). While this is an estimate of complex hydrologic processes, the 65 percent cover is a defensible target for forest protection in rural densities (see Figure 1.8) (Booth et al., 2002).

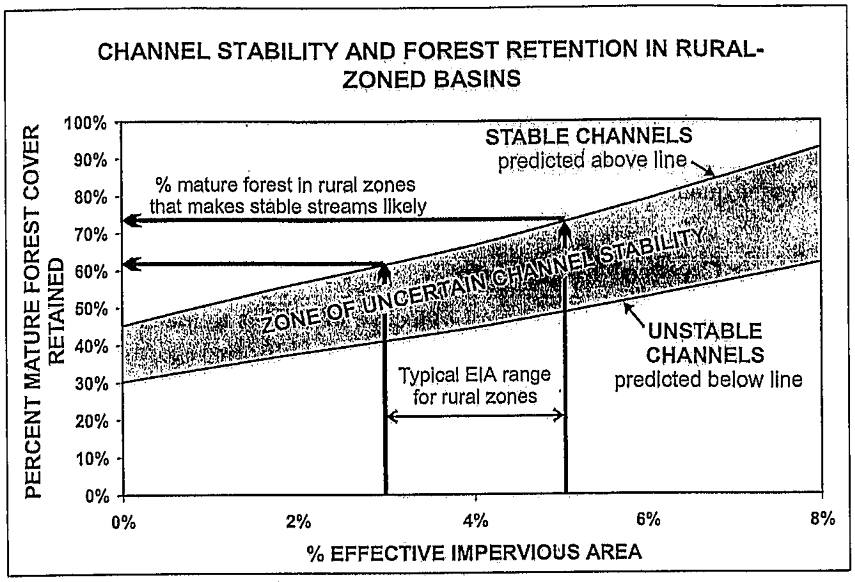


Figure 1.8 Modeled channel stablity plotted by percent forest cover retained and percent EIA (Booth et al., 2002).

Forested glacial outwash soils produce less overland flow than forested till soil conditions during storm events. As a result, forest clearing and increased impervious surface coverage can produce relatively larger peak-flows and increases in volume on outwash soils without adequate infiltration practices (Booth et al., 2002). The impact of concentrating infiltration facilities at a single location on outwash soils is not known; however, shallow subsurface flows may alter hydrologic characteristics if the development and facility are located proximate to a headwater stream.

Stormwater pollutant treatment is required when infiltrating stormwater on outwash soils from pollution generating surfaces (Washington Department of Ecology [Ecology], 2001). Processing pollutants in a facility that collects storm flows from an entire development can significantly increase infrastructure requirements and costs. Accordingly, 65 percent native soil and vegetation protection and *application of dispersed LID infiltration practices* is recommended for protecting stream and wetland habitat in the forested outwash soil and the rural setting.

1.4.3.2 Medium and high-density settings (6 or more dwelling units per acre)

The 65 percent target for mature native vegetation coverage may be achievable in medium and high-density settings by applying multifamily, cottage, or condominium type development. Sixty-five percent native vegetation and soil protection is not feasible with conventional single family detached housing at such densities. In the higher density setting, *comprehensive application of LID practices* is necessary to reduce the hydrologic changes and pollutant loads to surface and ground waters where less forest protection area is possible (see Chapter 3: Site Planning and Layout for design strategies).

Initial research modeling experimental, medium-density, residential LID designs indicates that pre-development hydrologic conditions may be approximated on soils with low infiltration rates when using the full suite of LID practices and 40 to 50 percent open space protection (CH2M HILL, 2001). In this difficult type of development scenario it is essential to apply a full complement of LID practices. Soil enhancement, bioretention, open conveyance, dispersion to open space, minimal excavation foundation systems, aggregate storage under paving, and roof water harvesting techniques must be integrated into the design to minimize hydrologic impacts. Eliminating the roof water contribution through roof water harvesting systems is essential for achieving the LID flow objective where higher density projects are located on soils with low infiltration rates.

1.4.4 Flow Control Objective and Department of Ecology's *Stormwater Management Manual for Western Washington*

This document or the flow control objective recommended in this manual does not supercede Ecology's 2005 *Stormwater Management Manual for Western Washington.* Where the Ecology manual is adopted, the minimum flow control standard for new development will be required to match 50 percent of the two-year event up to the full 50-year peak flows for a pre-developed forested condition (or prairie conditions if historic records indicate that as the native setting).

1.4.5 Site Design and Management Strategies to Meet Flow Control Objectives

The goal and flow control objective for LID are achieved through the following site design objectives. The objectives are grouped into four basic elements that constitute a complete LID design.

Conservation measures

- Maximize retention of native forest cover and restore disturbed vegetation to intercept, evaporate, and transpire precipitation.
- Preserve permeable, native soil and enhance disturbed soils to store and infiltrate storm flows.
- Retain and incorporate topographic site features that slow, store, and infiltrate stormwater.
- Retain and incorporate natural drainage features and patterns.

Site planning and minimization techniques

- Utilize a multidisciplinary approach that includes planners, engineers, landscape architects and architects at the initial phases of the project.
- Locate buildings and roads away from critical areas and soils that provide effective infiltration.
- Minimize total impervious surface area and eliminate effective impervious surfaces.

Distributed and integrated management practices

- Manage stormwater as close to its origin as possible by utilizing small scale, distributed hydrologic controls.
- Create a hydrologically rough landscape that slows storm flows and increases **time of concentration.**
- Increase reliability of the stormwater management system by providing multiple or redundant LID flow control practices.
- Integrate stormwater controls into the development design and utilize the controls as amenities–create a multifunctional landscape.
- Reduce the reliance on traditional conveyance and pond technologies.

Maintenance and Education

- Develop reliable and long-term maintenance programs with clear and enforceable guidelines.

- Educate LID project homeowners and landscape management personnel on the operation and maintenance of LID systems and promote community participation in the protection of those systems and receiving waters.

Subsequent sections of the manual–Chapter 3: Site Planning and Layout; Chapter 4: Vegetation Protection, Reforestation and Maintenance; Chapter 5: Site Clearing and Grading; Chapter 6: Integrated Management Practices; and Chapter 7: Flow Modeling Guidance–will provide information on low impact development tools and techniques that can be used to meet the objectives and strategies listed above. The manual outlines many of the tools available for designing a low impact development system, but it does not provide an exhaustive list of practices. The LID approach is creative and designers must consider the attributes of individual sites in the context of the local jurisdiction and community setting. Designers should apply sound science, an interdisciplinary approach and, at times, unique applications to meet LID goals and objectives. See Table 1.2 for a list of some LID techniques.

Table 1.2 LID techniques (checked items are examined in this manual).

X	Site assessment	X	Maintenance		Downspout dispersion
X	Site planning and design	X	Amending construction site soils	X	Roof stormwater harvesting systems
X	Site phasing and fingerprinting	X	Permeable asphalt		Filter strips
X	Preserving native soils and vegetation	X	Permeable concrete		Media filtration
X	Clearing and grading	X	Permeable gravel pave systems		
X	Bioretention cells	X	Permeable pavers		
X	Sloped biodetention	X	Vegetated roofs		
X	Bioretention swales	X	Minimal excavation foundations		
	Tree box filters		Homeowner education		

While the focus of low impact development and this manual is to more effectively manage stormwater, LID can and should address other livability issues including:

- Residential road design that reduces traffic speeds and promotes walking and biking as alternative transportation methods.
- Development at appropriate densities that meets Growth Management Act goals, and increases access to, and connection between, public transportation modes.
- Subdivision layout and building design that promote interaction between neighbors and the connection to open space and recreation areas.

1.4.6 Low Impact Development in the Watershed Context

LID is a tool for retrofitting existing or constructing new commercial and residential development at the parcel and subdivision scale. Maintaining aquatic habitat, water quality, species of special concern, and healthy aquatic systems in general requires protection or restoration of processes (for example the movement of water and recruitment of large woody debris) and structures (forest canopy, soils, etc.) at the sub-watershed, watershed or regional scale.

To protect high quality, sensitive stream systems the following critical area designations and associated land use controls are necessary:

- Extensive and near continuous riparian buffer protection.
- Floodplain protection.
- Aggressive native forest and soil protection.
- Limit EIA to approximately 10 percent.

(Horner, May, Livingston, Blaha, Scoggins, Tims, Maxted, 2001 and May et al., 1997)

Where higher levels of EIA and development exist or are proposed and ecological function is good or impaired (but not entirely lost), several strategies can be employed for protection and enhancement including, but not limited to: forest and soil restoration; comprehensive drainage design addressing cumulative impacts and implementing regional stormwater control facilities; and other mitigation and enhancement measures (May et al., 1997).

To improve sub-watershed or regional scale ecosystem functions, basin assessments must evaluate the quality and sensitivity of resources, and the cumulative impacts of existing development, future growth and other activities in sub-watersheds. Through the assessment and planning process, managers should set priorities for resource protection for sub-watersheds based on resource sensitivity and growth pressures. Various landscape analysis tools are available that allow managers to assign appropriate densities and types of development based on the projected cumulative impacts of different land use scenarios.

1.4.7 Low Impact Development and Comprehensive Stormwater Management

LID does not compensate for the cumulative and adverse effects from road networks and other land clearing activities that occur outside the development site. Low impact development can, however, be used in the various sub-basin development scenarios to help achieve larger-scale, sub-watershed protection goals. Implemented comprehensively, native soil and vegetation protection, soil improvement, and increased on-site storage and infiltration capacity at the site level are necessary to protect or enhance larger-scale hydrologic function and other watershed attributes.

While LID works with and supports the effective implementation of regional stormwater management plans and land use planning under the Growth Management Act, it is not a substitute for these local government responsibilities. The use of LID techniques should be part of a local, comprehensive stormwater management program that includes:

- Adoption and use of Ecology's 2005 *Stormwater Management Manual for Western Washington* (or an alternative manual that is technically equivalent).
- Regular inspections of construction sites.
- Maintenance of temporary and permanent facilities.
- Source control.
- Elimination of illicit discharges.
- Identification and ranking of existing stormwater problems.
- Public education and involvement.
- Watershed or basin planning.
- Stable funding.
- Programmatic and environmental monitoring.

(Puget Sound Action Team, 2000)

2 Site Assessment

IN THIS CHAPTER...

Inventory and assessment of:

- *Soil analysis*
- *Hydrologic patterns and features*
- *Native forest and soil conservation areas*
- *Wetlands*
- *Riparian areas*
- *Floodplains*

Comprehensive inventory and assessment of on-site and adjacent off-site conditions are the initial steps for implementing low impact development (LID). The inventory and assessment process provides information necessary to implement the site planning and layout activities (examined in the next chapter) by identifying the current and estimating the pre-disturbance conditions. Specifically, the site assessment process should evaluate hydrology, topography, soils, vegetation, and water features to identify how stormwater moves through the site prior to development. The site design should align roads, lots, and structures and implement construction practices to preserve and utilize these features to retain natural hydrologic functions. In almost all cases, low impact development requires on-site inventory and assessment and cannot be properly planned and implemented through map reconnaissance alone.

The site assessment process should evaluate hydrology, topography, soils, vegetation, and water features to identify how stormwater moves through the site prior to development.

Jurisdictions in the Puget Sound region have various requirements for identification and assessment of site characteristics and site plan development. Some or all of the following existing conditions are included by most local governments for identification and evaluation:

Geotechnical/soils	Streams	Wetlands
Floodplains	Lakes	Closed depressions
Springs/seeps	Other minor drainage features	Groundwater
Existing hydrologic patterns	Slope stability and protection	Geology
Habitat conservation areas	Aquifer recharge areas	Topography
Vegetation/forest cover	Anadromous fisheries impacts	Existing development
Erosion hazard areas	Offsite basin and drainage	Down-stream analysis

(King County, 1998; Washington State Department of Community, Trade and Economic Development, 2003; and Washington State Department of Ecology, 2001)

Inventory and evaluation to successfully implement an LID project will include some or all of the above existing conditions depending on the physical setting and regulatory requirements; however, the objective of the analysis and the level of detail necessary may vary. This section presents six steps in the LID site evaluation process that are essential and will likely require more focused attention than in a conventional project. Management recommendations for wetlands, riparian management areas, and floodplains are provided at the end of each evaluation step. Management recommendations for soils, hydrologic features, and native soil and vegetation protection areas are provided in subsequent chapters focusing on those issues.

2.1 Soil Analysis

LID requires detailed understanding of site soils. In-depth soil analyses in appropriate locations are often necessary to determine operating infiltration rates for two primary reasons: (1) LID emphasizes evaporation, storage, and infiltration of stormwater in smaller-scale facilities distributed throughout the site; and (2) on sites with mixed soil types, the LID site plan should locate impervious areas over less permeable soils and preserve and utilize permeable soils for infiltration.

2.1.1 Inventory and Assessment

Methods recommended for determining infiltration rates fall into two categories:

- Texture or grain size analysis using U.S. Department of Agriculture (USDA) Soil Textural Classification (Rawls survey) or ASTM D422 Gradation Testing at Full Scale Infiltration Facilities.
- In-situ infiltration measurements using a Pilot Infiltration Test, small-scale test infiltration pits (septic test pits), and groundwater monitoring wells.

Grain size analysis and infiltration tests present important but incomplete information. Soil stratigraphy should also be assessed for low permeability layers, highly permeable sand/gravel layers, depth to groundwater, and other soil structure variability necessary to assess subsurface flow patterns. Soil characterization for each soil unit (soil strata with the same texture, color, density, compaction, consolidation and permeability) should include:

- Grain size distribution.
- Textural class.
- Percent clay content.
- Cation exchange capacity.
- Color/mottling.
- Variations and nature of stratification.

(Ecology, 2001)

A few strategically placed soil test pits are generally adequate for initial site assessment. Pit locations are determined by topography, estimated soil type, hydrologic characteristics, and other site features. Consult a geotechnical engineer or soil scientist for initial assessment and soil pit recommendations.

A more detailed soil pit assessment is necessary once the preliminary site layout with location of LID stormwater controls is determined. Specific recommendations for assessing infiltration rates for bioretention areas and permeable paving installations are located in sections 6.1: Bioretention Areas and 6.3: Permeable Paving.

For management of on-site soils, see Section 6.2: Amending Construction Site Soils.

Assessing highly permeable gravel conditions

Special considerations are necessary for areas with highly permeable gravel. Signs of high groundwater will likely not be present in gravel lacking finer grain material such as sand and silt. Test pit and monitoring wells may not show high groundwater levels during low precipitation years. Accordingly, sound professional judgment, considering these factors and water quality treatment needs, is required to design multiple and dispersed infiltration facilities on sites with gravel deposits *(personal communication, Larry West, January 2004).*

2.2 Hydrologic Patterns and Features

Hydrology is a central design element that is integrated into the LID process at the initial site assessment and planning phase. Using hydrology as a design element begins by identifying and maintaining on-site hydrologic processes, patterns, and physical features (streams, wetlands, native soils and vegetation, etc.) that influence those patterns.

2.2.1 Inventory and Assessment

In addition to identifying prominent hydrologic features, additional analysis will likely be required to adequately assess water movement over and through the site including:

- Identify and map minor hydrologic features including seeps, springs, closed depression areas, and drainage swales.
- Identify and map surface flow patterns during wet periods, and identify signs of duration and energy of storm flows including vegetation composition, and erosion and deposition patterns.
- If seasonally high groundwater is suspected and if soil test pits do not provide sufficient information to determine depth to groundwater, map groundwater table height and subsurface flow patterns in infiltration and dispersion areas using shallow monitoring wells. Note: in many sites, shallow hand-augured monitoring wells can be installed at low cost.

For management of on-site hydrologic features see Section 1.4.5: Site Design and Management Strategies, Section 2.5: Riparian Management Areas, Chapter 3: Site Planning and Layout, and Chapter 5: Clearing and Grading.

The conservation and use of on-site native soil and vegetation for stormwater management is a central principle for an LID design.

2.3 Native Forest and Soil Conservation Areas

The conservation and use of on-site native soil and vegetation for stormwater management is a central principle of LID design. Protecting these features accomplishes three objectives: (1) reducing total impervious area; (2) increasing stormwater storage, infiltration, and evaporation; and (3) providing potential dispersion areas for stormwater. In addition to maintaining natural hydrologic processes, forest protection can provide other benefits including critical habitat buffers, open space, and recreation opportunity.

2.3.1 Inventory and Assessment

The following are steps to conduct a basic inventory and assessment of the function and value of on-site native vegetation:

- Identify any forest areas on the site and identify species and condition of ground cover and shrub layer, as well as tree species, **seral stage**, and canopy cover.
- Identify underlying soils utilizing soil pits and soil grain analysis to assess infiltration capacity. See Soil Analysis section above and consult a geotechnical engineer for site-specific analysis recommendations.

Soil surveys and vegetation surveys are necessary to determine baseline conditions, establish long-term management strategies, and determine appropriate application of dispersion techniques if stormwater is directed to the protection area.

For management of native vegetation and soil protection areas see Chapter 4: Vegetation Protection, Reforestation and Maintenance.

Steep slope and shoreline bluff considerations

Special care must be taken when developing on or near steep slopes, including coastal bluffs, especially those composed of layers of unconsolidated glacial sediment that occur in many areas of Puget Sound. Clearing of vegetation, increasing surface runoff, and hydraulic loading through infiltration of surface runoff can destabilize these areas, and in some cases lead to dramatic slope failures. A detailed analysis of the site's geology and hydrology should be prepared by a qualified professional prior to site clearing and development.

2.4 Wetlands

Determining appropriate assessment and management protocols for wetlands requires clear goals and objectives, as well as estimates of pre-development and evaluation of current conditions. Appropriate goals and objectives are determined through the development application process and involve government permitting entities, consultants, and the developer. Core assessment and management objectives for a project that is in a drainage basin with a wetland designated as high quality and sensitive should include: (1) protect native riparian vegetation and soils; (2) protect diverse native wetland habitat characteristics to support the native assemblage of wetland biota; and (3) maintain or approximate pre-development hydrology and **hydroperiod** within the wetland. Note: Washington State Department of Ecology (Ecology) guidance includes Category 1 or 2 wetlands and Category 3 wetlands that meet most of the criteria in Appendix 1-D of Ecology's 2005 *Stormwater Management Manual for Western Washington* (SMMWW) as high quality and sensitive. If the project is within the drainage area for a wetland that can be considered for structural or hydrological modification then the development may incorporate use of the wetland into the stormwater management strategy. Ecology recommends use of criteria in the 2005 SMMWW Appendix 1-D page D-10 for wetland assessment guidelines.

2.4.1 Inventory and Assessment

The following steps should be used as a starting point to adequately inventory and provide an assessment of wetlands:

- Identify wetland category using local jurisdiction regulations and/or Ecology's *Washington State Wetlands Rating System for Western Washington.*
- If the wetland qualifies for protection:
    - o Measure existing hydroperiods and estimate future hydroperiods resulting from the proposed development.
    - o Identify hydrologic pathways into and out of wetland.
    - o Determine whether the wetland has breeding, native amphibians (conduct survey in spring).

2.4.2 Management

- If the wetland qualifies for protection, utilize LID strategies to increase stormwater infiltration and storage on the project site in order to meet the following guidelines (Azous and Horner, 2001):
    - o The increase or decrease of the pre-development mean monthly water level fluctuations should be maintained to less than 5 inches.
    - o The increase or decrease of 6 inches or more to the pre-development water level fluctuation should be restricted to less than 6 times during an average year.
    - o The duration of stage excursions of 6 inches or more above or below the pre-development water level fluctuations should not exceed 72 hours per excursion.
    - o Total dry period (when pools dry down to the soil surface everywhere in the wetland) should not increase or decrease by more than two weeks in any year.
    - o For priority peat wetlands, the duration of stage excursions above or below the pre-development water level fluctuations should not exceed 24 hours in a year.
    - o For wetlands inhabited by breeding amphibians, increases or decreases in pre-development water level fluctuations should not exceed 3 inches for more than 24 hours in any 30-day period.

- o See Guidesheets 2A through 2D in Appendix 1-D of the 2005 SMMWW for additional criteria.
- Designate buffer widths consistent with best available science (see Washington State Department of Community, Trade and Economic Development *Critical Areas Assistance Handbook*, 2003 and *Citations of Recommended Sources of Best Available Science*, 2002).
- Map wetlands and wetland buffer areas on all plans and delineate these areas on the site with fencing to protect soils and vegetation from construction damage. Fencing should provide a strong physical and visual barrier of high strength plastic or metal and be a minimum of 3 to 4 feet high (see Ecology 2001 SMMWW BMP C103 and C104). Silt fencing, or preferably a compost berm, is necessary in addition to, or incorporated with, the barrier for erosion control.
- Install signs to identify and explain the use and management of the natural resource protection areas.
- See Riparian Management Areas section for additional management strategies within buffer areas.

2.5 Riparian Management Areas

The riparian zones are defined as areas adjacent to streams, lakes, and wetlands that support native vegetation adapted to saturated or moderately saturated soil conditions. When there is adequate mature vegetation, stable land-form, and large woody debris, riparian areas perform the following functions:

- Dissipate stream energy and erosion associated with high flow events.
- Filter sediment, capture bedload, and aid in floodplain development.
- Improve flood water retention and groundwater recharge.
- Develop diverse ponding and channel characteristics that provide habitat necessary for fish and other aquatic life to spawn, feed, and find refuge from flood events.
- Provide vegetation litter and nutrients to the aquatic food web.
- Provide habitat for a high diversity of terrestrial and aquatic biota.
- Provide shade and temperature regulation.
- Provide adequate soil structure, vegetation, and surface roughness to slow and infiltrate stormwater delivered as precipitation or low velocity sheet flow from adjacent areas (Prichard et al., 1998).

2.5.1 Inventory and Assessment

The objective for riparian area assessment and management is to protect, maintain, and restore mature native vegetation cover that provide the above functions and structures. See sections 2.4: Wetlands, 2.6: Floodplains, and Chapter 4: Vegetation Protection, Reforestation, and Maintenance for assessing the extent and quality of riparian management areas (RMA) in various settings.

2.5.2 Management

RMAs are used to buffer streams, lakes, wetlands and other aquatic resources from adjacent land disturbance. While managing RMAs to maintain vegetation cover, soils, and stable land-form to buffer aquatic resources is standard practice, managing overland stormwater flows from adjacent developed is not the primary function of

Riparian Management Areas

Adequately sized and maintained riparian management areas are necessary for protecting streams, lakes, and wetlands from many of the impacts of surrounding urbanizati riparian management areas. However, if the riparian area will receive storm flow, the following minimum riparian buffer design criteria are recommended to dissipate, infiltrate, and remove pollutants from overland flow:

- Maintain overland flow as sheet flow and do not allow stormwater entering or within buffers to concentrate.
- Maintain (and restore if necessary) mature, native plant community and soils within the buffer.
- Designate buffer widths consistent with best available science (see Washington State Department of Community, Trade and Economic Development *Critical Areas Assistance Handbook,* 2003 and *Citations of Recommended Sources of Best Available Science,* 2002).
- If buffer averaging is used, the following minimum site features and objectives should be considered when determining the extent of the buffer: soils, slope, vegetation, pollutant loads, water quantity and quality targets, and sensitivity of resource.
- Map RMAs on all plans, and delineate with fencing to protect soils and vegetation from construction damage. Fencing should provide a strong physical and visual barrier of high strength plastic or metal and be a minimum of 3 to 4 feet high (see Ecology 2005 SMMWW BMP C103 and C104). Silt fencing, or preferably a compost berm, is necessary in addition to, or incorporated with, the barrier for erosion control.
- Install signs to identify and explain the use and management of the natural resource protection areas.
- Buffers should include 100-year floodplain, wetlands and steep slopes adjacent to streams, and the channel migration zone.
- Flow velocities reaching and within buffer areas should not exceed 1 ft/second.
- Unrestricted overland flow distance should not exceed 150 ft for pervious areas and 75 ft for impervious areas before reaching buffers (Schueler, 1995).
- See Chapter 7: Flow Modeling Guidance for detailed dispersion guidelines.
- Do not allow effective impervious surface within the buffer.
- Activity within the RMA should be limited to:
  - passive, confined recreation (i.e., walking and biking trails) constructed from pervious surfaces.
  - platforms for viewing streams, lakes, and wetlands constructed with techniques to minimize disturbance to soils and vegetation.
- Establish a long-term management entity and strategy to maintain or enhance the structural integrity and capacity of the buffer to protect water quality and habitat.

2.6 Floodplains

The objective for floodplain area assessment and management is to maintain or restore: (1) the connection between the stream channel, floodplain, and off channel habitat; (2) mature native vegetation cover and soils; and (3) pre-development hydrology that supports the above functions, structures, and flood storage.

2.6.1 Inventory and Assessment

The following steps, at a minimum, should be used to inventory and provide baseline conditions of the floodplain area:

- Identify the 100-year floodplain and channel migration zone.
- Identify active channel.
- Inventory composition and structure of vegetation within the floodplain area.

2.6.2 Management

- Map the extent of the 100-year floodplain or channel migration zone on all plans and delineate these areas on the site with fencing to protect soils and vegetation from construction damage. Fencing should provide a strong physical and visual barrier of high strength plastic or metal and be a minimum of 3 to 4 feet high (see Ecology 2005 SMMWW BMP C103 and C104). Silt fencing, or preferably a compost berm, is necessary in addition to, or incorporated with, the barrier for erosion control.
- See Section 2.5: Riparian Management Areas for additional management strategies.
- Install signs to identify and explain the use and management of the natural resource protection areas.

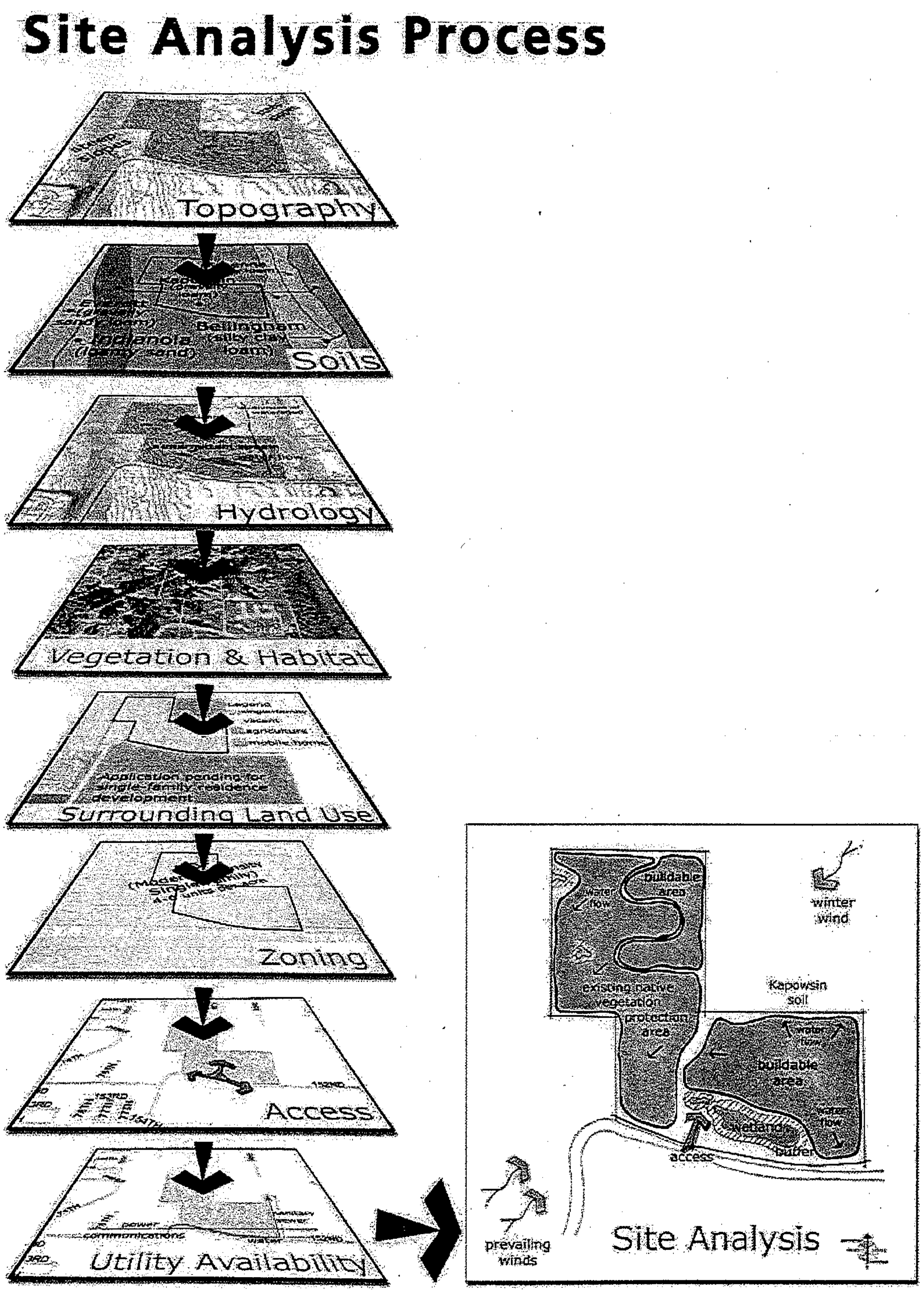
A project should not be considered low impact development if it is located within the 100-year floodplain or channel migration zone.

2.7 Site Mapping Process

Through the assessment process, map layers are produced to delineate important site features. The map layers are combined to provide a composite site analysis that guides the road layout and overall location and configuration of the development envelopes (see figures 2.1 and 2.2, following pages). See Chapter 3: Site Planning and Layout for details on utilizing assessment information for site design.

Figure 2.1 Composite site analysis for a residential subdivision.

Graphic by AHBL Engineering



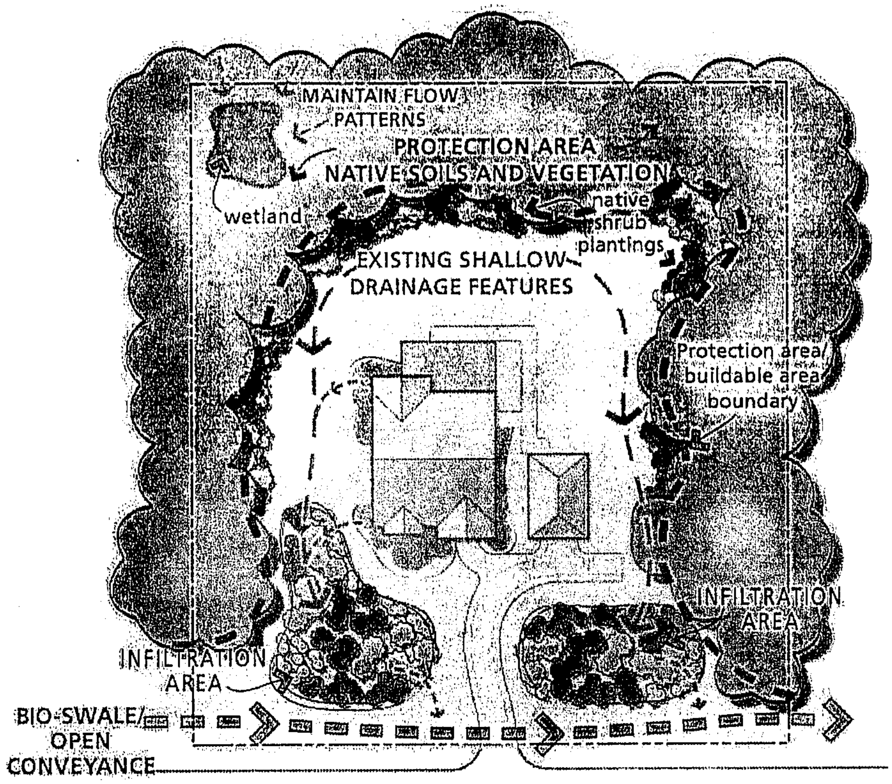


Figure 2.2 Large lot composite site analysis.

Graphic by AHBL Engineering

3 Site Planning and Layout

IN THIS CHAPTER...

- *Road, driveway, and parking layouts for medium to high density subdivisions, large lots, and commercial sites*
- *Road crossings*
- *Street trees*
- *Lot layout for medium to high density clusters, large lots, and rural clusters*
- *Building design*

Site assessment and site planning are iterative processes. Existing and native environmental conditions strongly influence the extent and location of the development envelope for a low impact development (LID) project. The regulatory, market, and architectural context of the location are integrated with the site assessment findings to produce a road and lot configuration that strategically uses site features for isolating impervious surface and dispersing and infiltrating storm flows. As site planning progresses and details for roads, structures, and LID practices are considered, additional evaluation of site conditions may be necessary.

Context is essential for developing any successful residential or commercial project. The designer must consider the appropriate plat design and housing type given the existing character and possible future conditions of the area when developed. Architectural considerations influence how the project integrates with the surroundings while at the same time creating neighborhood identity (personal communication Len Zickler, January 2004). A low impact development project incorporates these same design considerations; however, the following stormwater and other environmental management elements are elevated to equal standing:

Hydrology is an organizing principle that is integrated into the initial site assessment and planning phases.

- Hydrology is an organizing principle that is integrated into the initial site assessment and planning phases.
- Individual LID practices are distributed throughout the project site and influence the configuration of roads, house lots, and other infrastructure.
- LID practices are amenities that provide multiple functions, including aesthetic landscaping, visual breaks that increase a sense of privacy within a variety of housing densities, and a design element (of equal importance to architectural and plat design) that promotes neighborhood identity.

Assessment of natural resources outlined in the previous section will produce a series of maps identifying streams, lakes, wetlands, buffers, steep slopes, and other hazard areas, significant wildlife habitat areas, and permeable soils offering the best available infiltration potential. Maps can be combined as GIS or CAD layers to delineate the best areas to direct development. Building sites, road layout, and stormwater infrastructure should be configured within these development areas to minimize soil and vegetation disturbance and take advantage of a site's natural stormwater processing capabilities.

Initial site management strategies include:

- Establish limits of disturbance to the minimum area required for roads, utilities, building pads, landscape areas, and the smallest additional area needed to maneuver equipment.
- Map and delineate natural resource protection areas with appropriate fencing and signage to provide protection from construction activities.
- Meet and walk the property with the owner, engineers, landscape architects, and others directing project design to identify problems and concerns that should be evaluated for developing the site plans.
- Meet and walk the property with equipment operators prior to clearing and grading to clarify construction boundaries and limits of disturbance (see Chapter 4: Vegetation Protection, Reforestation, and Maintenance and Chapter 5: Site Clearing and Grading for more detailed information).

The following section is organized under two main categories: (1) Roads, Driveways and Parking; and (2) Lot Layout. The first category is examined by medium to high density, individual large lot, and commercial type development, and the second by medium to high density cluster, rural cluster, and large lot development.

3.1 Roads, Driveways and Parking

Residential roads in the early 1900s were primarily laid out in grid patterns to allow efficient access to services and transit, and were dominated by a mix of uses including pedestrian, bicycle, and vehicle transportation. The grid configuration has evolved over the past century to modified grids and the current prevailing designs that use curvilinear layouts with relatively disconnected loops and cul-de-sacs. The transition has been driven primarily by the increased mobility offered by the automobile and the perceived safety and privacy of dead end roads (Canadian Mortgage and Housing Corporation [CMHC], 2002).

An analysis in south Puget Sound found that the transportation component of the suburban watershed accounts for approximately 60 percent of the total impervious area (City of Olympia, 1995). At the national level, the American Association of State Highway and Transportation Officials (AASHTO) estimates that the urban and rural local access roads typically account for 65 to 80 percent of the total road network (AASHTO, 2001). Design standards for roads in residential areas focus on efficient and safe movement of traffic and rapid conveyance of stormwater. As a result, streets contribute higher storm flow volumes and pollutant loads to urban stormwater than any other source area in residential developments (City of Olympia, 1995 and Bannerman, Owens, Dodds and Hornewer, 1993).

Streets contribute higher storm flow volumes and pollutant loads to urban stormwater than any other source area in residential developments.

The overall objectives for low impact development road designs are:

- Reduce **total impervious area** (TIA) by reducing the overall road network coverage.
- Minimize or eliminate effective impervious area (EIA) and concentrated surface flows on impervious surfaces by reducing or eliminating hardened conveyance structures (pipes or curbs and gutters).
- Infiltrate and slowly convey storm flows in roadside bioretention cells and swales, and through permeable paving and aggregate storage systems under the pavement.

- Design the road network to minimize site disturbance, avoid sensitive areas, and reduce fragmentation of landscape.
- Create connected street patterns and utilize open space areas to promote walking, biking and access to transit and services.
- Provide efficient fire and safety vehicle access.

Local access and small-collector road design is influenced at the individual parcel and subdivision scale and is the focus of this section. Road design is site specific; accordingly, this section does not recommended specific road designs. Instead, the strengths and weaknesses of different road layouts are examined in the context of LID to assist designers in the process of providing adequate transportation systems while reducing impervious surface coverage.

3.1.1 Medium to High Density Subdivision and Planned Community

Road layout

The Urban Land Institute (ULI), Institute of Transportation Engineers (ITE), National Association of Home Builders, and American Society of Civil Engineers state in a 2001 collaborative publication that: "The movement of vehicles is only one of a residential street's many functions. A residential street is also part of its neighborhood and provides a visual setting for the homes as well as a meeting place for residents." Additionally, ULI recommends that the land area devoted to streets should be minimized (National Association of Home Builders [NAHB], American Society of Civil Engineers, Institute of Transportation Engineers, and Urban Land Institute, 2001). These recommendations are derived primarily from a livability and safety perspective; however, the guidelines also integrate well with the low impact development design approach.

Designs for residential roads generally fall into three categories: grid, curvilinear and hybrids. Figure 3.1 illustrates the grid and curvilinear road layouts and Table 3.1 summarizes the strengths and weaknesses of the grid and curvilinear approaches.

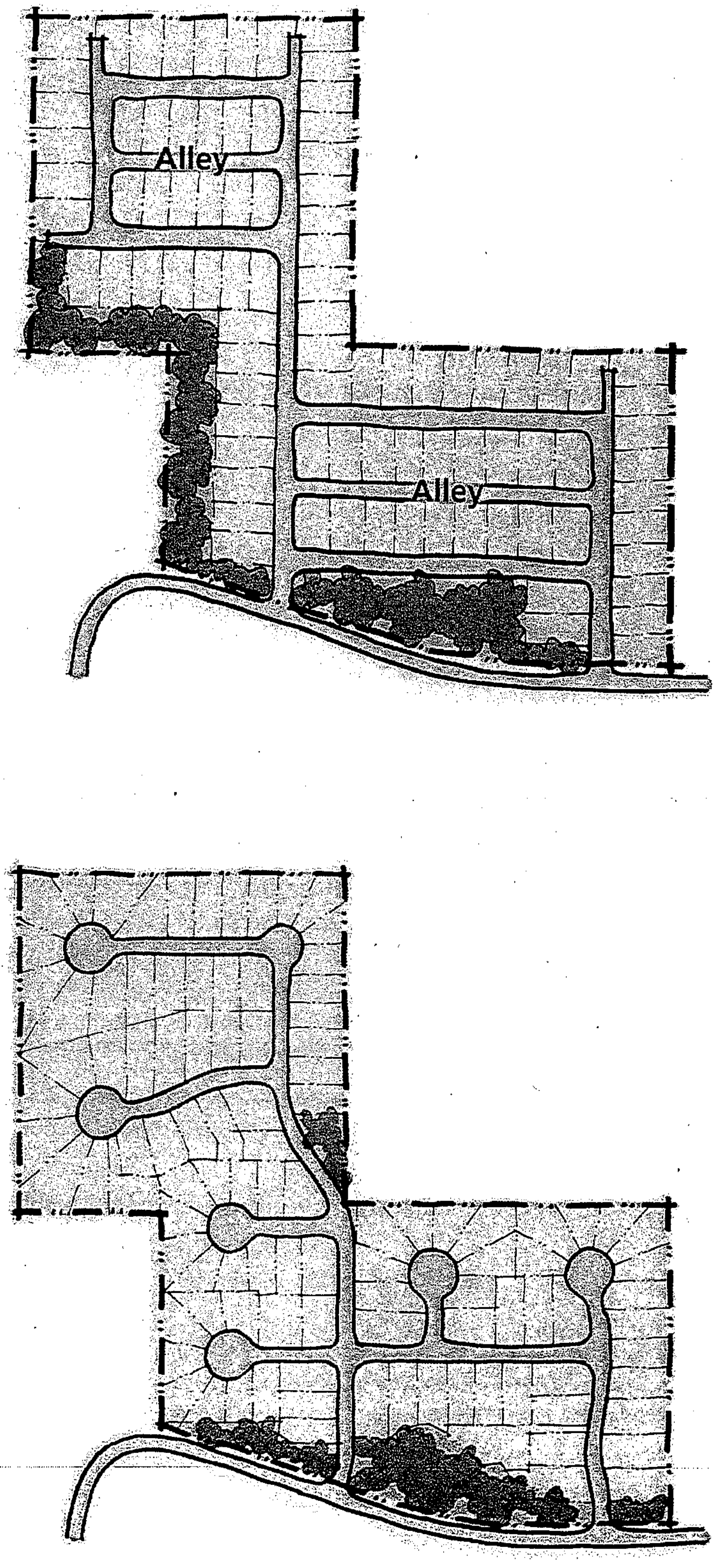
Table 3.1 Strengths and weaknesses of the grid and curvilinear approaches.

Road Pattern	Impervious Coverage	Site Disturbance	*Biking, Walking, Transit	Safety	Auto Efficiency
Grid	27-36% (Center for Housing Innovation, 2000 and CMHC, 2002)	less adaptive to site features and topography	promotes by more direct access to services and transit	may decrease by increasing traffic throughout residential area	more efficient—disperses traffic through multiple access points
Curvilinear	15-29% (Center for Housing Innovation, 2000 and CMHC, 2002)	more adaptive for avoiding natural features, and reducing cut and fill	generally discourages through longer, more confusing, and less connected system	may increase by reducing through traffic in dead end streets	less efficient—concentrates traffic through fewer access points and intersections

** Note: biking, walking and transit are included for livability issues and to reduce auto trips and associated pollutant contribution to receiving waters.*

Figure 3.1
Top: Typical grid road layout with alleys.
Lower: Typical curvilinear road layout with cul-de-sacs.

Graphic by AHBL Engineering



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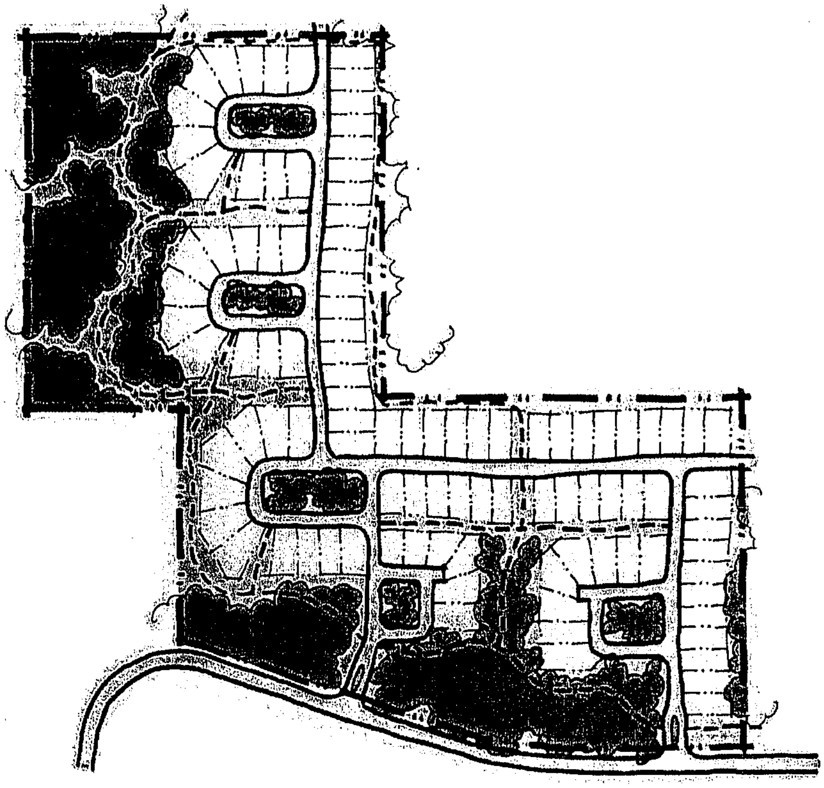


Figure 3.2 Hybrid, or open space, road layout.

Graphic by AHBL Engineering

The grid and curvilinear systems both have advantages and disadvantages. However, grid street patterns with alleys have one large drawback in the LID context: grids typically require 20 to 30 percent more total street length than curvilinear patterns (CWP, 1998 and Table 3.1). Recently, planners have integrated the two prevalent models to incorporate the strengths of both. These street networks have several names including open space, hybrid, and headwater street plans (Figure 3.2).

The following are strategies used to create road layouts in medium to higher density low impact residential developments that provide effective transportation networks and minimize impervious surface coverage:

- Cluster homes to reduce overall development envelope and road length (Schueler, 1995).
- Narrow lot frontages to reduce overall road length per home (see Figure 3.2) (Schueler, 1995).
- For grid or modified grid layouts, lengthen street blocks to reduce the number of cross streets and overall road network per home, and provide mid-block pedestrian and bike paths to reduce distances to access transit and other services (Center for Housing Innovation [CHI], 2000).
- Where cul-de-sacs are used, provide pedestrian paths to connect the end of the street with other pathways, transit or open space (Ewing, 1996).
- Provide paths in open space areas to increase connection and access for pedestrians and bicyclists (Ewing, 1996).
- Create pedestrian routes to neighborhood destinations that are direct, safe and aesthetically pleasing (CHI, 2000).

- Reduce road widths and turn around area coverage (see road widths, parking and driveway sections).
- Reduce front yard set backs to reduce driveway length.
- Minimize residential access road right-of-way to only accommodate needed infrastructure next to road (residential access roads are rarely widened) (Schueler, 1995).
- Eliminate, or reduce to an absolute minimum, all stream crossings.

The road and pedestrian pathway networks in figures 3.3 and 3.4 illustrate multifunctional road layout designs.

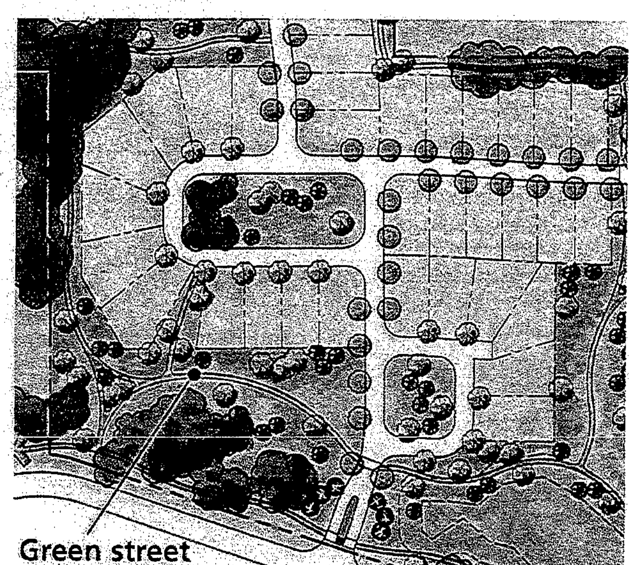


Figure 3.3 Loop road design.
Graphic by AHBL Engineering

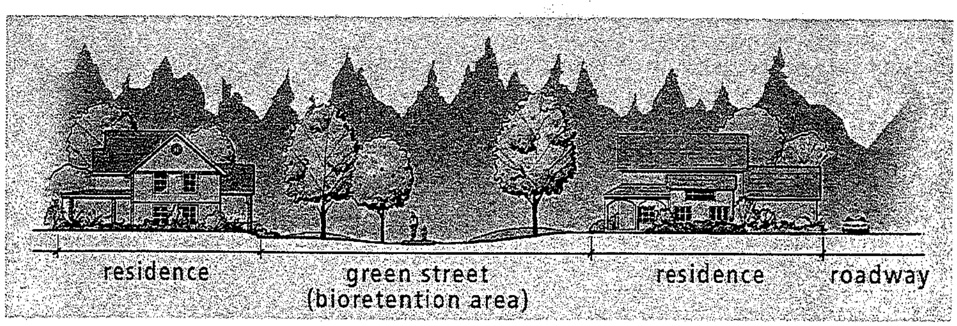


Figure 3.4 Green street section.
Graphic by AHBL Engineering

The loop road design:

- Minimizes impervious road coverage per dwelling unit.
- Provides adequate turning radius for fire and safety vehicles.
- Provides through traffic flow with two points of access.
- Provides a large bioretention area in the center of the loop and a visual landscape break for homes facing the road.

The open space pathways between homes (green streets):

- Provide a connected pedestrian system that takes advantage of open space amenities.

- Provide additional stormwater conveyance and infiltration for infrequent, large storm events.

The Sherbourne project in figures 3.5 and 3.6 is designed with one access to the development; however, ample traffic flow through the subdivision is provided by the loop and along home frontages, allowing for easier movement of fire and safety vehicles. Open space in the center of the loop provides stormwater storage, a visual landscape break for homes facing the road, and a creative example of integrating a regulatory requirement with a site amenity.

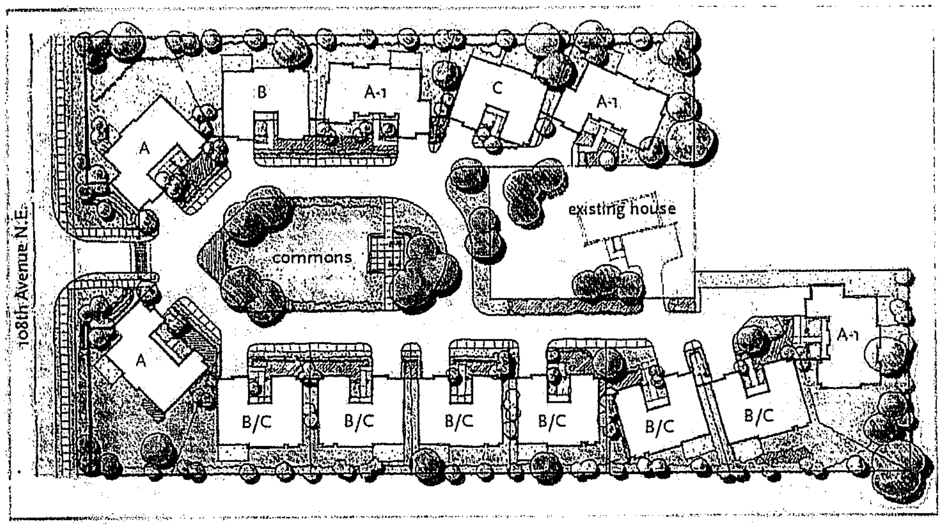


Figure 3.5 Sherbourne plan view.
Graphic courtesy of Mithun

Figure 3.6 Combined commons and stormwater facility at Sherbourne.
Photo by Colleen Owen

Road width

Residential road widths and associated impervious surface have, for various reasons, increased by over 50 percent since the mid-1900's (Schueler, 1995). Road geometry, including road widths, are derived primarily from two sources: American Association of State Highway Transportation Officials (AASHTO) and ITE (Schueler, 1995). A standardized guideline for residential roads that responds to general safety, traffic flow, emergency access, and parking needs is often adopted from these sources to fit various development scenarios. For example, AASHTO recommends 26-foot pavement widths and 50-foot right of way for residential roads across various density and traffic load demands. Additionally, many communities continue to equate wider streets with better and safer streets. Studies indicate, however, that residential accidents may increase exponentially as the street gets wider, and narrower roads that reduce traffic speeds are safer (CHI, 2000; NAHB et al., 2001; and Schueler, 1995).

Total and effective impervious area can be significantly reduced by determining specific traffic, parking, and emergency vehicle access needs and designing for the narrowest width capable of meeting those requirements. Examples of narrow street widths tailored to traffic need from different U.S. locations and from ULI are provided in Table 3.2. Reducing the street width from 26 to 20 feet reduces TIA by 30 percent. In the road network represented in Figure 3.2, the 30 percent reduction represents a storm flow reduction from 15,600 cubic feet to 12,000 cubic feet for a 2 inch 24-hour storm.

Table 3.2 Examples of narrow street widths from various jurisdictions.

Location or Source	Street Type	Width	Volume (ADT*)	Parking
Buck's County, PA	local access	18 ft	200	none
Buck's County, PA	residential collector	20 ft	200-1,000	none
Portland, OR	queuing	26 ft	not reported	both sides
ULI	shared driveway (5-6 homes)	16 ft	not reported	not reported
ULI	local	18 ft	not reported	one side only
ULI	local	22-26 ft	not reported	both sides
ULI	alley	12 ft	not reported	none
City of Seattle	local access	14 ft	125 (from traffic counts)	none
City of Seattle	local access	20 ft	250 (from traffic counts)	one side
City of Olympia	local access (2-way)	18 ft	0-500	none
City of Olympia	local access (queuing)	18 ft	0-500	one side alternating
City of Olympia	neighborhood collector	25 ft	500-3000	one side alternating

** ADT: Average daily traffic*

Turnarounds

Dead end streets with excessive turn around area (particularly cul-de-sacs) can needlessly increase impervious area. In general, dead end or cul-de-sac streets should be discouraged; however, a number of alternatives are available where topography, soils or other site specific conditions suggest this road design. Thirty-foot radius turnarounds are adequate for low volume residential roads servicing primarily passenger vehicles (AASHTO, 2001 and NAHB et al., 2001). A 40-foot radius with a landscaped center will accommodate most service and safety vehicle needs when a minimum 20-foot internal turning radius is maintained (Schueler, 1995). The turning area in a cul-de-sac can be enhanced by slightly enlarging the rear width of the radius. A hammerhead turnaround requires vehicles to make a backing maneuver, but this inconvenience can be justified for low volume residential roads servicing 10 or fewer homes (NAHB et al., 2001). A 10-foot reduction in radius can reduce impervious coverage by 44 percent and the hammerhead configuration generates approximately 76 percent less impervious surface than the 40-foot cul-de-sac. Four turnaround options and associated impervious surface coverage are presented in Figure 3.7.

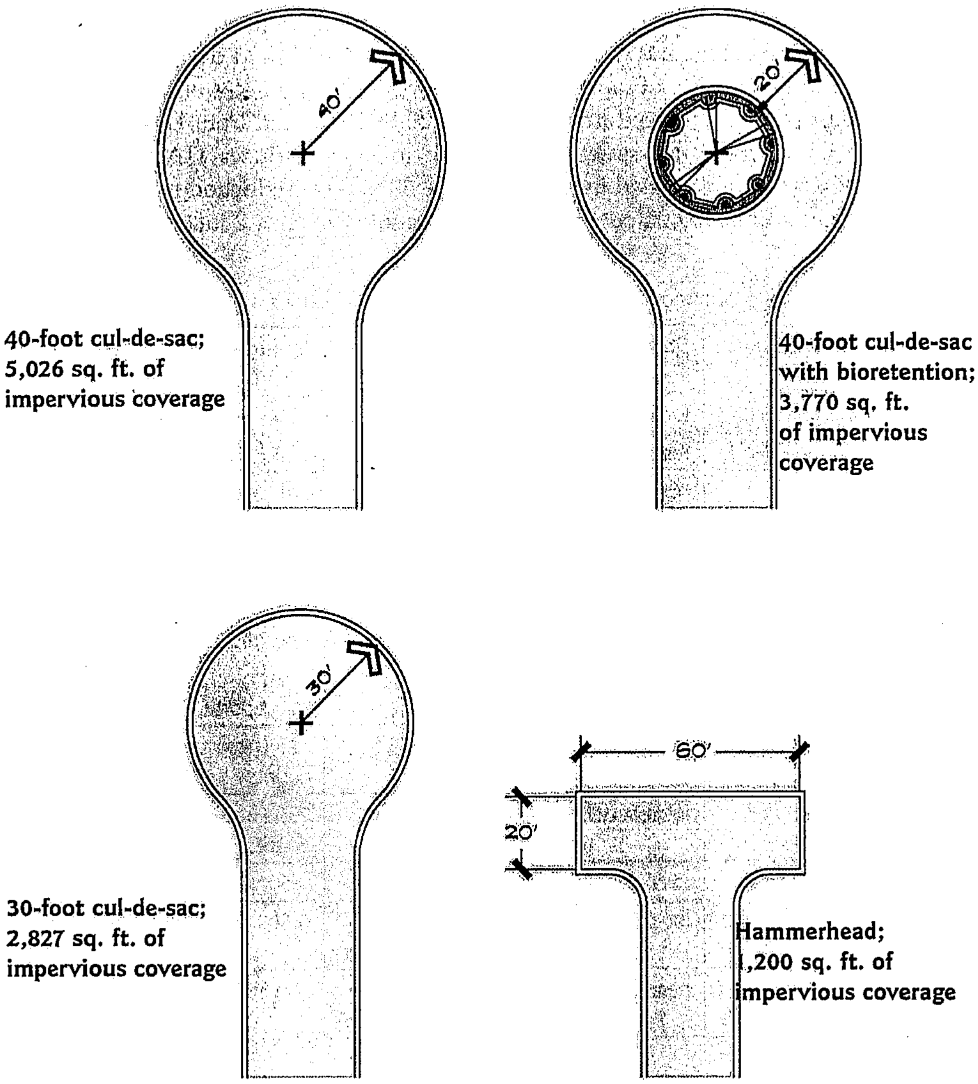


Figure 3.7 Turnaround areas and associated impervious coverage.

Graphic by AHBL Engineering

Islands in cul-de-sacs should be designed as bioretention or detention facilities. Either a flat concrete reinforcing strip or curb-cuts can be utilized to allow water into the facility (see Section 6.3: Permeable Paving for details).

The loop road configuration is an alternative to the dead end street and provides multiple access points for emergency vehicles and residents (see figures 3.3 and 3.5). For similar impervious surface coverage, the loop road has the additional advantage of increasing available storm flow storage within the loop compared to the cul-de-sac design.

Parking

Many communities require 2 to 2.5 parking spaces per dwelling. Driveways and garages can accommodate this need in most cases, and providing curb side parking on both sides of the street and two travel lanes (i.e., the 36-foot wide local residential street) creates excess impervious surface. Parking needs and traffic movement can be met on narrowed roads where one or two on-street parking lanes serve as a traffic lane (queuing street) (CWP, 1998). Figure 3.8 provides two examples of queuing streets for local residential streets.

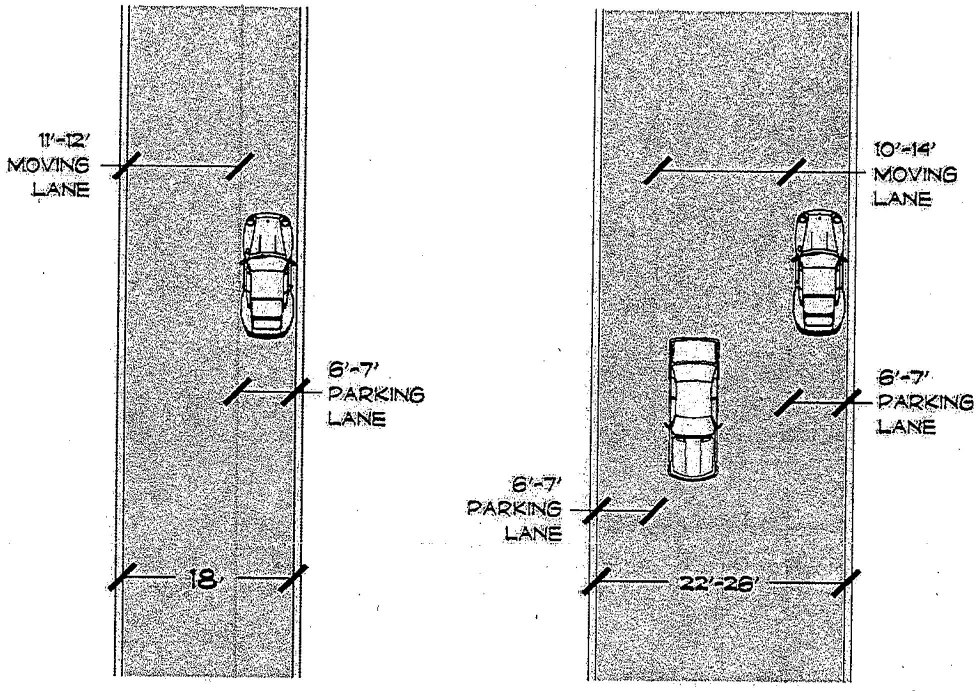


Figure 3.8
Left: 18-ft street with parking on one side.
Right: 22 to 26-ft street with parking on both sides.
(Adapted from National Association of Home Builders et al., 2001)

In higher density residential neighborhoods with narrow roads and where no on-street parking is allowed, pullout parking can be utilized. Pullouts (often designed in clusters of 2 to 4 stalls) should be strategically distributed throughout the area to minimize walking distances to residences. Depending on the street design, the parking areas may be more easily isolated and the impervious surface rendered ineffective by slightly sloping the pavement to adjacent bioretention swales or bioretention cells (Figure 3.9).

All or part of pullout parking areas, queuing lanes or dedicated on-street parking lanes can be designed using permeable paving (see Figure 3.10 for an example design). Permeable asphalt, concrete, pavers, and gravel pave systems can support the load requirements for residential use, reduce or eliminate storm flows from the surface, and may be more readily acceptable for use on lower-load parking areas by jurisdictions hesitant to use permeable systems in the travel way. Particular design and management strategies for subgrade preparation and sediment control must be implemented where pullout parking or queuing lanes receive storm flows from adjacent impervious areas (see Section 6.3: Permeable Paving for details).

Traffic calming strategies

Several types of traffic calming strategies are used on residential roadways to reduce vehicle speeds and increase safety. These design features also offer an opportunity for storm flow infiltration and/or slow conveyance to additional LID facilities downstream (figures 3.11 and 3.12).

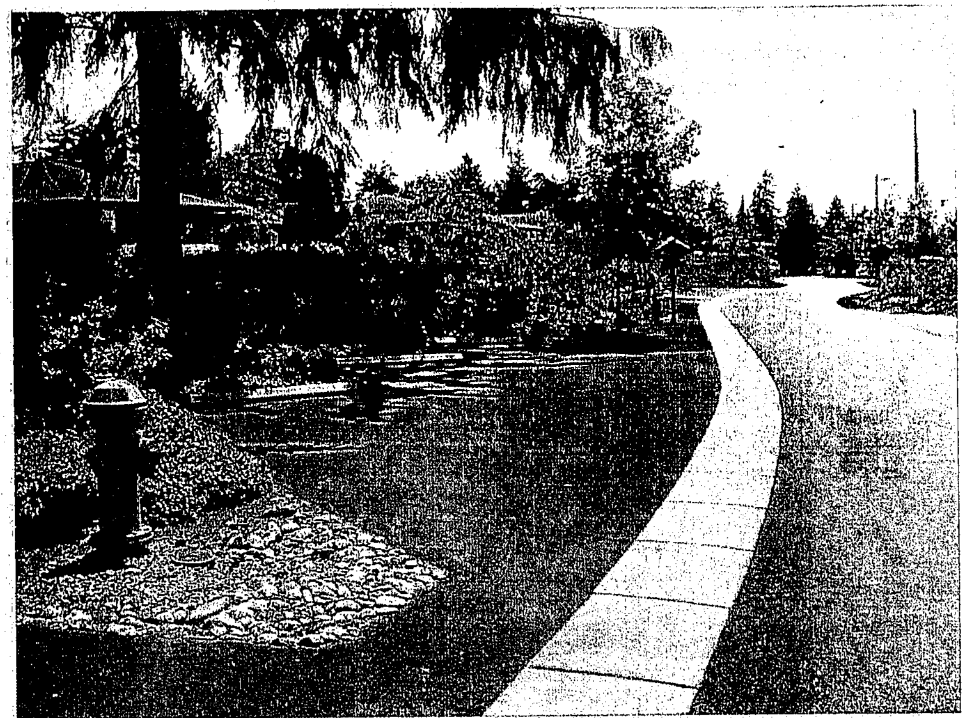


Figure 3.9 Pullout parking adjacent to a 14-foot residential access road, Seattle.
Photo by Colleen Owen

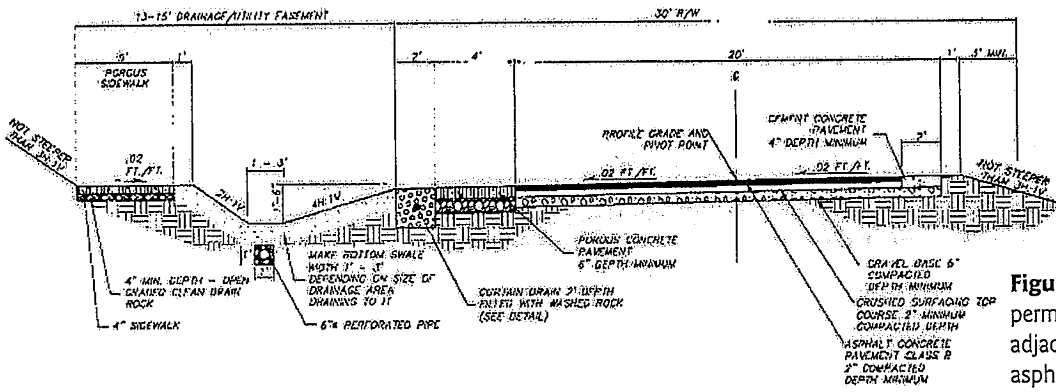


Figure 3.10 Four-foot permeable paving section adjacent to conventional asphalt roadway.
Courtesy of Pierce County Department of Public Works and Utilities

Alleys

Alleys should be the minimum width required for service vehicles, constructed of permeable paving materials, and allow any surface flows to disperse and infiltrate to adjacent bioretention swales, shoulders or yards (Figure 3.13). Strategies to reduce TIA associated with alleys include:

Maximum alley width should be 10 to 12 feet with 14- to 16-foot right-of-ways respectively.

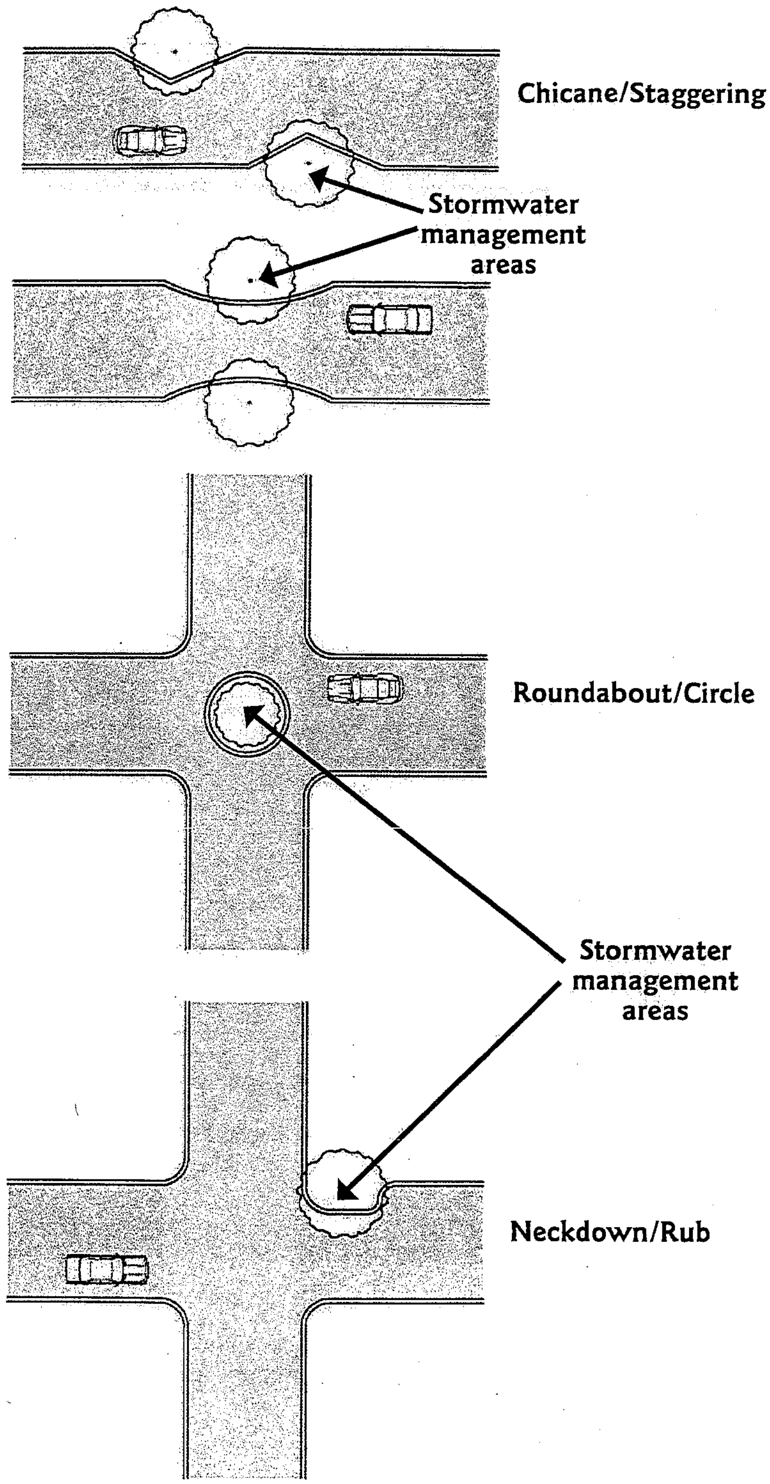
Several permeable paving materials are applicable for low speeds and high service vehicle weights typically found in alleys including:

- Gravel pave systems.
- Permeable concrete.
- Permeable pavers.
- Systems integrating multiple permeable paving materials.

See Section 6.3: Permeable Paving for details.

Figure 3.11 Combination stormwater management and traffic calming. (Note: These areas are slightly lower than road surface.)

Graphic by AHBL Engineering



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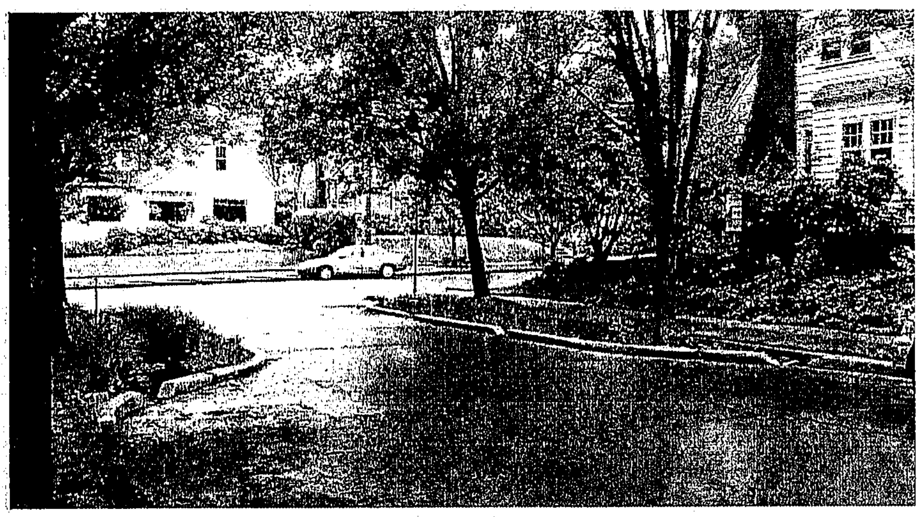

Figure 3.12 Siskiyou project in Portland, Oregc uses traffic calming design to manage stormwater. Note curb cuts that allow stormwater to enter bioretention area in narrow section of road.

Photo by Erica Guttman

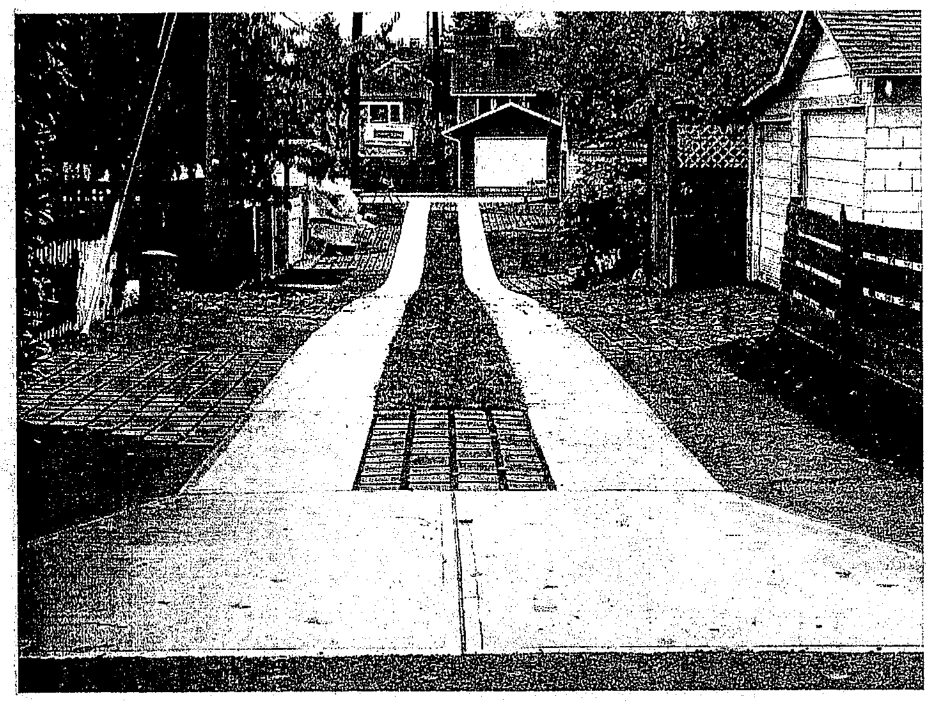

Figure 3.13 Vancouver, BC Country Lane alley uses a combination of concrete wheel strips, permeable pavers, reinforced plastic grid with grass, and under-drains to attenuate storm flows and create an aesthetic design objective.

Photo by Curtis Hinman

Driveways

As much as 20 percent of the impervious cover in a residential subdivision can be attributed to driveways (CWP, 1998). Several techniques can be used to reduce impervious coverage associated with driveways including:

- Shared driveways provide access to several homes and may not have to be designed as wide as local residential roads (Figure 3.14). Recommendations range from 9 to 16 feet in width serving 3 to 6 homes (NAHB et al., 2001 and Prince George's County, Maryland, 2000). A hammerhead or other configuration that generates minimal impervious surface may be necessary for turnaround and parking area.
- Minimize front yard setbacks to reduce driveway length.
- Reduce minimum driveway width from 20 (common standard) to 18 feet. Driveways can be reduced further to 10 feet with a bulb-out at the garage.

Figure 3.14 Issaquah Highlands shared driveway. *Photo by Curtis Hinman*

- Use permeable paving materials and aggregate storage under wearing surface.
- Limit impervious surface to two tracks with remainder in reinforced grass or other pervious surface (California strips).
- Direct surface flow from driveways to compost-amended soils, bioretention areas or other dispersion and infiltration areas (see Section 6.2: Amending Construction Site Soils and Section 6.1: Bioretention Areas for details).

Sidewalks

Many jurisdictions require sidewalks on both sides of residential roads for safety and perceived consumer demand. Studies indicate that pedestrian accident rates are similar in areas with sidewalks on one or both sides of the street (CWP, 1998). Limited assessments suggest that there is no appreciable market difference between homes with sidewalks on the same side of the street and homes with sidewalks on the opposite side of the road (CWP, 1998). The Americans with Disabilities Act (ADA) does not require sidewalks on both sides, but rather at least one accessible route from public streets (WAC 51-40-1100, 2003). Impervious surface coverage generated by sidewalks can be reduced using the following strategies:

- Reduce sidewalk to a minimum of 44 inches (ADA recommended minimum) or 48 inches (AASHTO, 2001 and NAHB et al., 2001 recommended minimum).
- For low speed local access roads eliminate sidewalks or provide sidewalks on one side of the road. A walking and biking lane, delineated by a paint stripe, can be included along the roadway edge.
- Design a bioretention swale or bioretention cell between the sidewalk and the street to provide a visual break and increase the distance of the sidewalk from the road for safety (NAHB et al., 2001).
- Install sidewalks at a two percent slope to direct storm flow to bioretention swales or bioretention cells—do not direct sidewalk water to curb and gutter or other hardened roadside conveyance structures.
- Use permeable paving material to infiltrate or increase time of concentration of storm flows (see Section 6.3: Permeable Paving for details).

Figure 3.15 Permeable concrete walkway and parking area on Whidbey Island.

Courtesy of Greg McKinnon

3.1.2 Low Density/Large Lots

Dispersion

Low density or large lot development offer increased opportunities or land area to integrate LID dispersion, storage, and infiltration strategies. The greater distances between residences can, however, increase the overall road network and total impervious coverage per dwelling (Schueler, 1995). Preserving or restoring native soils and vegetation along low density road networks and driveways, and dispersing storm flows to those areas offers a low cost and effective LID strategy. Designs for dispersion should minimize surface flow velocities and not concentrate storm flows.

The strategies for road, driveway, parking and other LID designs appropriate in medium to high density settings (see Section 3.1.1) can be applied in large lot settings as well.

Dispersion flow control credit

See Chapter 7 for design of dispersion techniques and flow control guidelines when using the Western Washington Hydrologic Model.

Driveways

Shared driveways are applicable in large lot as well as higher density settings. Figure 3.16 is a large lot conservation design for protecting open space and uses shared driveways to access homes.

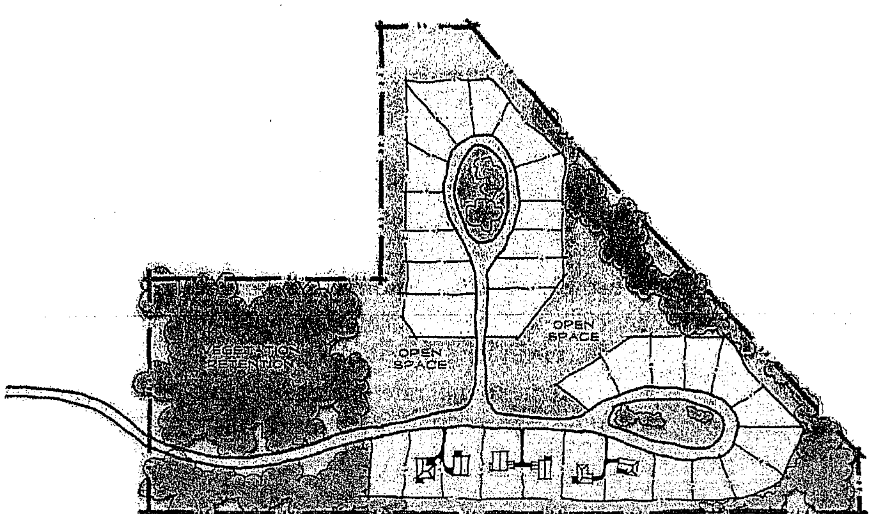

Figure 3.16 Large lot cluster design with shared driveway.

Graphic by AHBL Engineering

3.1.3 Commercial

Parking

Parking lots and roof tops are the largest contributors to impervious surface coverage in commercial areas. Typical parking stall dimensions are approximately 9 to 9.5 feet by 18.5 to 19 feet, totaling 166.5 and 180.5 square feet respectively (Schueler, 1995 and City of Olympia, 1995). Considering the total space associated with each stall including overhangs, access isle, curbs, and median islands, a parking lot can require up to 400-square feet per vehicle or approximately one acre per 100 cars (CHI, 2000). The large effective impervious coverage associated with parking areas accumulates high pollutant loads from atmospheric deposition and vehicle use (auto pollutant contributions can be particularly heavy during stopping and starting a vehicle). As a result, commercial parking lots can produce greater levels of petroleum hydrocarbons and trace metals (cadmium, copper, zinc, lead) than many other urban land uses (Schueler, 1995 and Bannerman et al., 1993).

Many jurisdictions specify parking demand ratios as a minimum number of spaces that must be provided for the development type, number of employees, gross floor area or other parking need indicator. While parking infrastructure is a significant expense for commercial development, providing excess parking is often perceived as necessary to attract (or not discourage) customers. As a result, minimum standards are often exceeded in various regions of the U.S. by 30 to 50 percent (Schueler, 1995). In a local study, the city of Olympia found that 70 percent of all parking lots surveyed had at least 25 percent additional capacity during normal and peak hours (City of Olympia, 1995). The same study concluded that a 20 percent reduction in parking stalls was feasible without significantly impacting business activity.

The city of Olympia found that 70 percent of all parking lots surveyed had at least 25 percent additional capacity during normal and peak hours.

Capping parking demand ratios to reflect actual need is the most effective of several methods used to reduce impervious coverage in parking areas. In a commercial parking area selected in the Olympia study (526 stalls), a 20 percent reduction (105 stalls) would reduce surface flows by approximately 4,000 cubic feet for a typical two-year event (City of Olympia, 1995).

To reduce impervious coverage, storm flows, and pollutant loads from commercial parking areas, several LID strategies can be employed including:

- Assess parking demand ratios to determine if ratios are within national or, if available, actual local ranges (Schueler, 1995).
- Establish minimum and maximum or median parking demand ratios and allow additional spaces above the maximum ratio only if parking studies indicate a need for added capacity.
- Dedicate 20 to 30 percent of parking to compact spaces (typically 7.5 by 15 feet).
- Use a diagonal parking stall configuration with a single lane between stalls (reduces width of parking isle from 24 to 18 feet and overall lot coverage by 5 to 10 percent) (Schueler, 1995).
- Where density and land value warrant, or where necessary to reduce TIA below a maximum allowed by land use plans, construct underground, under building or multi-story parking structures.
- Use permeable paving materials for the entire parking area or, at a minimum, for spillover parking that is used primarily for peak demand periods (Figure 3.17).

- Integrate bioretention into parking lot islands or planter strips distributed throughout the parking area to infiltrate, store, and/or slowly convey storm flows to additional facilities.
- Encourage cooperative parking agreements to coordinate use of adjacent or nearby parking areas that serve land uses with non-competing hours of operation–for example a cooperative agreement between a church and an office or retail store (City of Olympia, 1995).

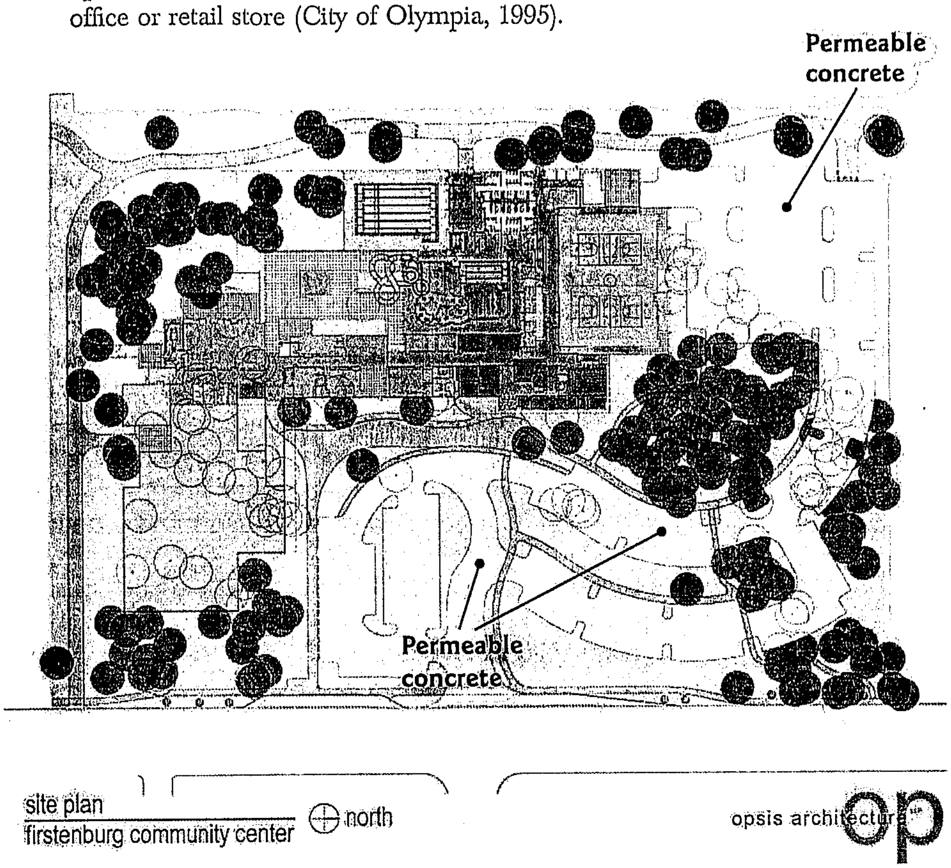

Figure 3.17 Firstenburg project in Vancouver, Washington includes 100,000 square feet of permeable concrete. *Courtesy of 2020 Engineering*

3.2 Road Crossings

Numerous studies have correlated increased total impervious area with declining stream and wetland conditions (Azous and Horner, 2001; Booth et al., 2002; May et al., 1997). Recent research in the Puget Sound region suggests that the number of stream crossings per stream length may be a relatively stronger indicator of stream health (expressed through Benthic Index of Biotic Integrity) than TIA (Avolio, 2003). In general, crossings place significant stress on stream ecological health by concentrating and directing storm flows and contaminants to receiving waters through associated outfall pipes, fragmenting riparian buffers, altering hydraulics, and disrupting in-channel processes such as meander migration and wood recruitment (Avolio, 2003 and May, 1997). Culvert and bridge design that place supporting structures in the floodplain or active channel confine stream flows. The confined flow often increases bank and bed erosion resulting in channel enlargement downstream of the structure (Avolio, 2003). Bank armoring associated with crossings further disrupts hydraulics and channel processes and can increase the impacts of all crossing types including less damaging bridge designs (Avolio, 2003).

> *Road crossings place significant stress on stream ecological health by directing concentrated storm flows and contaminants to receiving waters, fragmenting riparian buffers, altering hydraulics, and disrupting in-channel processes.*

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Improperly designed crossings using culverts can also inhibit or completely block fish passage. Design considerations for minimizing road crossing impacts include:

- Eliminate, or reduce to an absolute minimum, all stream crossings.
- Where stream crossings are unavoidable, bridges are preferable to culverts.
- Locate bridge piers or abutments outside of the active channel or channel migration zone.
- If culverts are utilized, install slab, arch or box type culverts, preferably using bottomless designs that more closely mimic stream bottom habitat.
- Utilize the widest possible culvert design to reduce channel confinement.
- Minimize stream bank armoring and establish native riparian vegetation and large woody debris to enhance bank stability and diffuse increased stream power created by road crossing structures. (Note: consult a qualified fluvial geomorphologist and/or hydrologist for recommendations.)
- All crossings should be designed to pass the 100-year flood event.
- Cross at approximately 90 degrees to the channel to minimize disturbance.
- Do not discharge storm flows directly from impervious surfaces associated with road crossing directly to the stream—disperse and infiltrate stormwater or detain and treat flows.

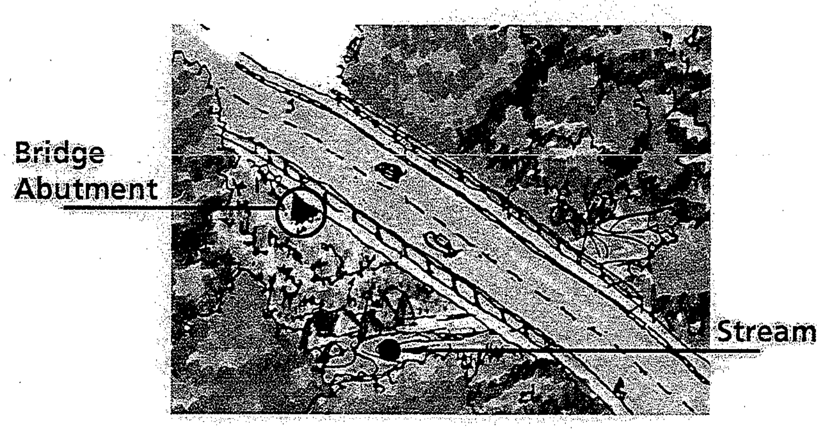


Figure 3.18 Minimal impact stream crossing. Locate abutments outside of active channel or channel migration zone. Cross at approximately 90° to channel to minimize shading and other disturbances.

Courtesy of Portland Metro Green Streets Program

3.3 Street Trees

Trees can be used as a stormwater management tool in addition to providing more commonly recognized benefits such as energy conservation, air quality improvement, and aesthetic enhancement. Tree surfaces (foliage, bark, and branches) intercept, evaporate, store or convey precipitation to the soil before it reaches surrounding impervious surfaces. In bioretention cells or swales, tree roots build soil structure that enhances infiltration capacity and reduces erosion (Metro, 2003).

Appropriate placement and selection of tree species is important to achieve desired benefits and reduce potential problems such as pavement damage by surface roots and poor growth performance. When selecting species, consider the following site characteristics:

- Available growing space.
- Type of soil and availability of water.
- Overhead wires.
- Vehicle and pedestrian sight lines.
- Proximity to paved areas and underground structures.

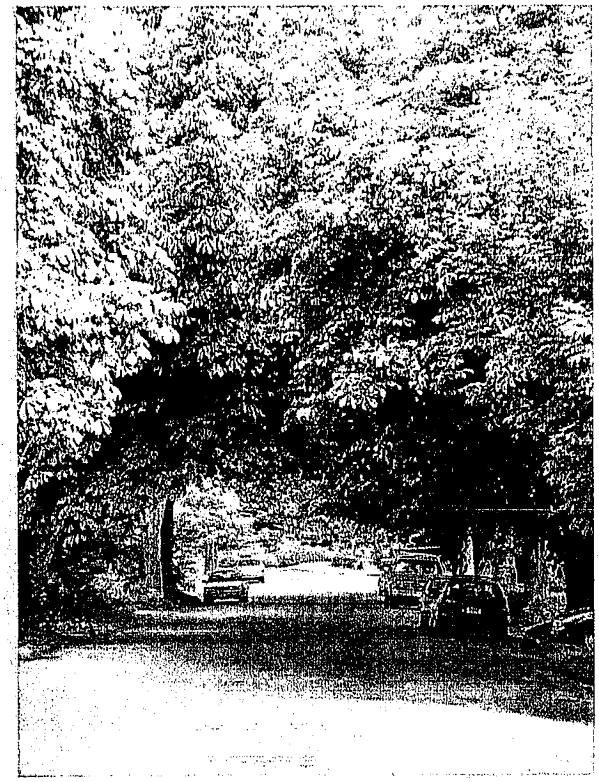


Figure 3.19 Street trees—Queen Anne neighborhoc Seattle.
Photo by Colleen Owen

- Proximity to neighbors, buildings, and other vegetation.
- Prevailing wind direction and sun exposure.
- Additional functions desired, such as shade, aesthetics, windbreak, privacy screening, etc.

Local jurisdictions often have specific guidelines for the types and location of trees planted along public streets or rights-of-way. The extent and growth pattern of the root structure must be considered when trees are planted in bioretention areas or other stormwater facilities with under-drain structures or near paved areas such as driveways, sidewalks or streets. Other important tree characteristics to consider when making a selection include:

- Longevity or life-span (ideally a street tree will be "long-lived", meaning it has a life span of 100 years or more. However, the longevity of a tree will need to be balanced with other selection priorities).
- Tolerance for urban pollutants.
- Growth rate.
- Tolerance to drought, seasonally saturated soils, and poor soils.
- Canopy spread and density (trees that provide a closed street canopy maximize interception and evapotranspiration).
- Foliage texture and persistence.

Appendix 1 lists the growth pattern and appropriate site characteristics for a variety of trees appropriate for street, parking lot, residential yard, and bioretention applications.

3.4 Lot Layout

Typical residential development determines lot size by dividing the total plat acreage, minus the roads and regulated sensitive areas, by the number of lots allowed under the applicable zoning. Most, if not all, of the site is cleared and graded. In contrast, LID projects employ clustering and other planning strategies to minimize site disturbance, maximize protection of native soil and vegetation, and permanently set aside the open tracts for multiple objectives including stormwater management. Four general objectives should guide the placement and orientation of lots for LID projects:

- Minimize site disturbance.
- Strategically locate lots for dispersing stormwater to open space areas.
- Orient lots and buildings to maximize opportunities for on-lot infiltration or open conveyance through bioretention swales or cells to downstream LID facilities.
- Locate lots adjacent to, or with views of, open space to improve aesthetics and privacy.

The following examines three prevalent development strategies applied in a low impact development context—medium to high density cluster, rural cluster, and large lot development.

3.4.1 Medium to High Density Cluster (4 or More Dwelling Units Per Acre)

Clustering is a type of development where buildings are organized together into compact groupings that allow for portions of the development site to remain in open space (Maryland Office of Planning, 1994). In the U.S., the primary focus of cluster development has been to preserve natural and cultural features, provide recreation, preserve rural character, and produce more affordable housing (Schueler, 1995).

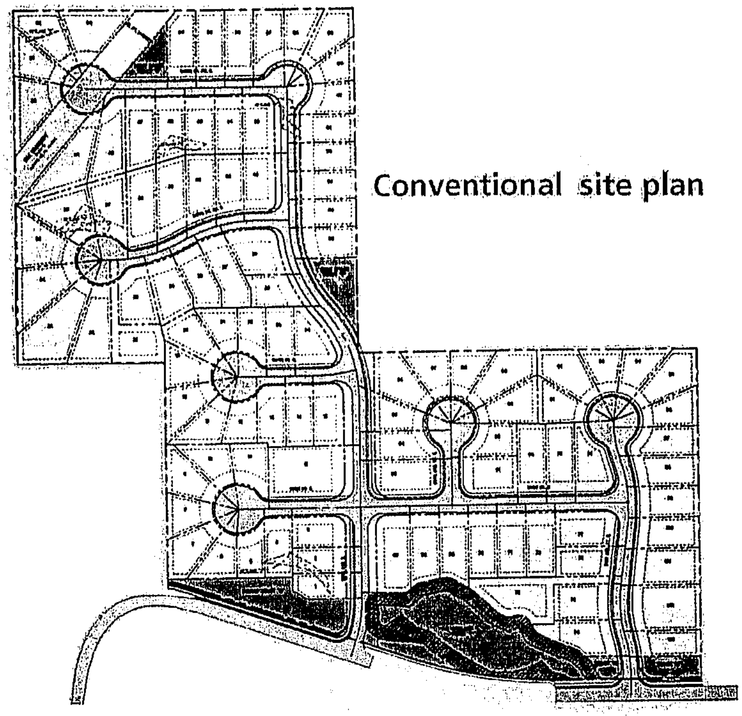
The LID cluster may include the above objectives; however, the primary purpose of the low impact development cluster is to minimize the development envelope, reduce impervious coverage, and maximize native soil and forest protection or restoration areas. Natural resource protection areas (the preferred strategy) are undisturbed conservation areas. Restoration areas (appropriate where land is or will be disturbed) can be enhanced through soil amendments and native planting to improve the hydrologic function of the site. Both can provide dispersion for overland flows generated in developed areas. Demonstration projects indicate that significant open space protection can still be achieved over conventional development projects designed with relatively small lot sizes when using cluster strategies (Figure 3.20).

Objectives for medium to high density clustering:

- Medium density (4 to 6 dwelling units per acre): reduce the development envelope in order to retain a minimum of 50 percent open space.
- High density (more than 6 dwelling units per acre): protect or restore to the greatest extent possible. Note: in medium to high density settings, reducing the development envelope and protecting native forest and soil areas will often require multifamily, cottage, condominium or mixed attached and detached single family homes.

Techniques to meet objectives for medium to high density clustering include:

- Minimize individual lot size (3,000 to 4,000 square-foot lots can support a medium sized home designed to occupy a compact building footprint).



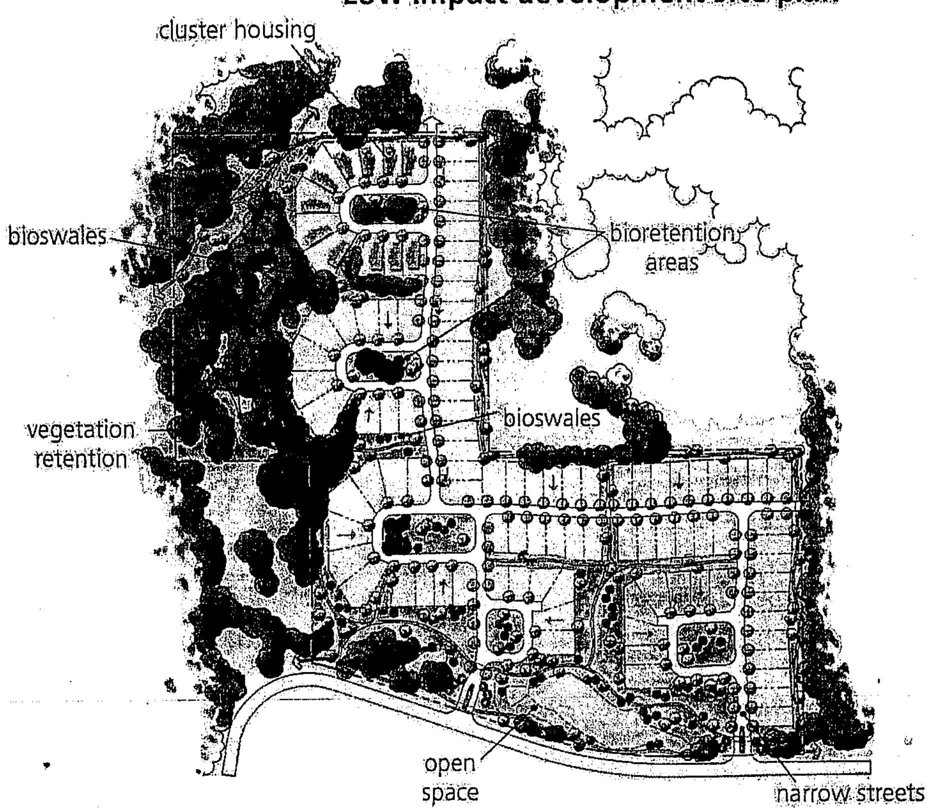


Figure 3.20 Conventional small lot development compared to LID cluster design.

Graphic by AHBL Engineering

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Figure 3.21 Example of medium- to high-density lot using low impact development practices.

Graphic by AHBL Engineering

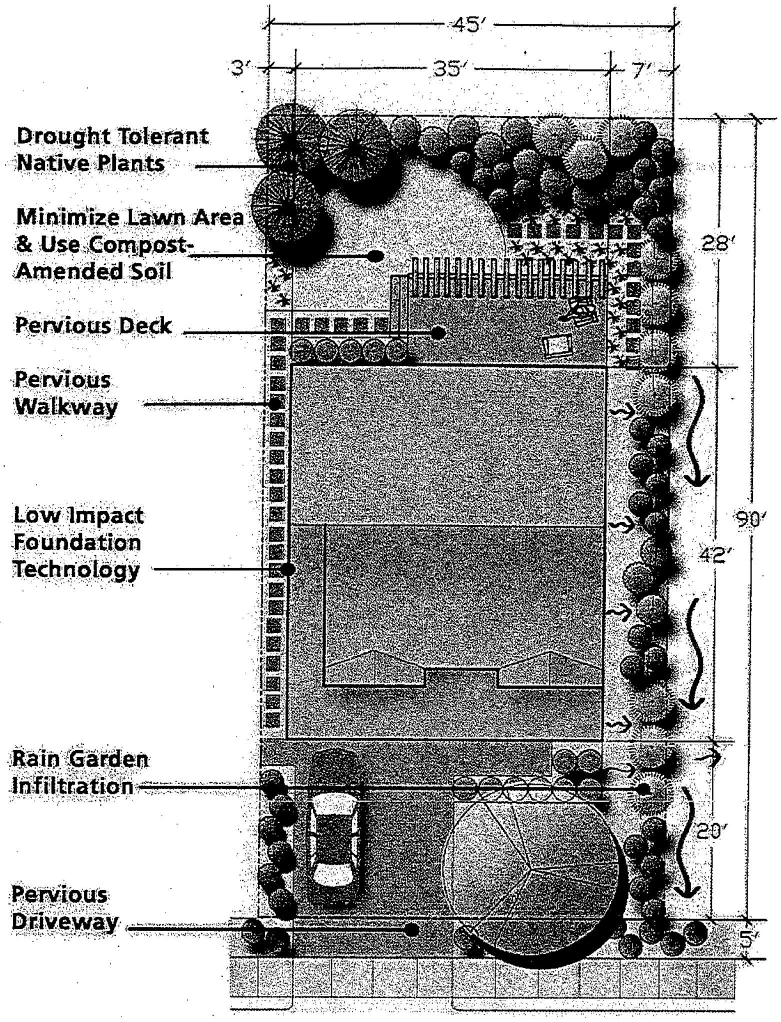
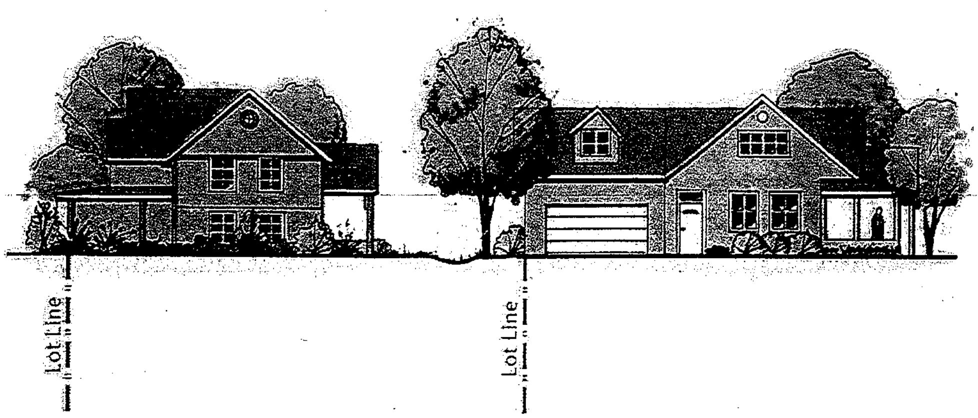


Figure 3.22 Zero lot line configuration.

Graphic by AHBL Engineering



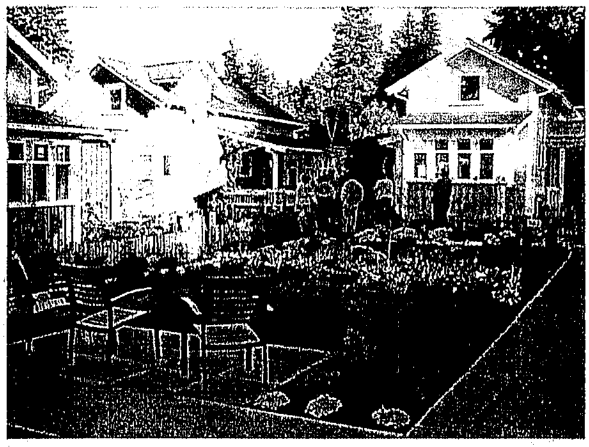


Figure 3.23 Shared courtyard in a cottage development in Seattle.
Photo by Curtis Hinman

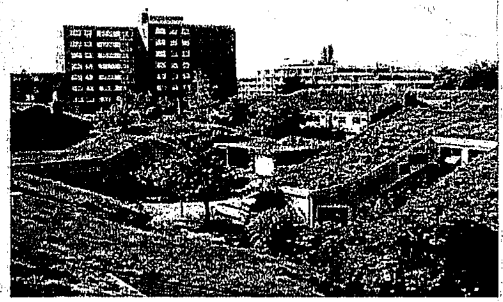


Figure 3.24 Cluster of homes designed with vegetated roofs in Berlin, Germany.
Photo courtesy of Patrick Carey

- Minimize setbacks. Examples of minimum setbacks include:
  - 25-foot front yard.
  - 3-foot side yard (minimum side yard set backs should allow for fire protection ladder access, and structures with narrow side yards should use fire resistant siding materials).
- Use zero lot line set back to increase side yard area (Figure 3.22).
- Use cottage designs for a highly compact development envelope.
- Amend disturbed soils to regain stormwater storage capacity (see Section 6.2: Amending Construction Site Soils).
- Drain rooftops to cisterns for non-potable reuse within the house or garden (see Section 6.6: Roof Rainwater Collection Systems).
- Utilize vegetated roof systems to evaporate and transpire stormwater (see Section 6.4: Vegetated Roofs).
- Lay out roads and lots to minimize grading to the greatest extent possible.
- Stormwater from lots not adjacent to forested/open space infiltration areas can be conveyed in swales or dispersed as low velocity (< 1fps) sheet flow to the infiltration areas.
- Orient lots to use shared driveways to access houses along common lot lines.
- To maximize privacy and livability within cluster developments, locate as many lots as possible adjacent to open space, orient lots to capture views of open space, and design bioretention swales and rain gardens as visual buffers.
- Set natural resource protection areas aside as a permanent tract or tracts of open space with clear management guidelines.

A little known, but effective, cluster strategy is Air Space Condominium design. In this design scenario (applicable for most single family residential development), the property is not divided into separate lots. Instead, designated areas, or air space, that include the dwelling and some additional yard space (optional) are available for purchase with the remaining property held in common and managed by a homeowners association. The stormwater management practices are held within an easement for local jurisdiction access and require a long-term management agreement followed by the homeowners. The advantage of the condominium classification is increased design flexibility including:

- The entire road network can be considered as driveway reducing design standards for road widths, curb and gutter, etc.
- No minimum lot size.
- Reduced overall development envelope.

Note: fire and vehicle safety requirements must still be satisfied.

3.4.2 Rural Cluster and Large Lot Development

Substantial reduction of impervious surfaces can be realized through clustering large lot development. In a study comparing 100-lot subdivision designs, the Maryland Office of State Planning found a 30 percent reduction in impervious surface when lot size was reduced from a typical rural density of 1.4 to 0.25 acres. Additional road network and driveway lengths are the primary reasons for increased imperviousness associated with large lot development (Delaware Department of Natural Resources and Environmental Control and the Environmental Management Center of the Brandywine Conservancy, 1997). The increased storm flows from the additional road network required to serve rural cluster and large lot designs should be dispersed to bioretention swales, adjacent open space, and/or lawn areas amended with compost (figures 3.25 and 3.26).

Objectives for rural clustering and large lots:

- Reduce the development envelope in order to retain a minimum of 65 percent of the site in native soil and vegetation.
- Reduce EIA to zero (fully disperse stormwater).

Medium to high density cluster guidelines can be used in large lot settings. The increased land area in the rural cluster and large lot scenarios offer additional opportunities including:

- Integrate bioretention and open bioretention swale systems into the landscaping to store, infiltrate, slowly convey, and/or disperse stormwater on the lot.
- Disperse road and driveway stormwater to adjacent open space and lawn areas (see Chapter 7: Flow Modeling Guidance for dispersion details).
- Maintain pre-development flow path lengths in natural drainage patterns.
- Preserve or enhance native vegetation and soil to disperse, store, and infiltrate stormwater.
- Disperse roof water across the yard and to open space areas or infiltrate roof water in infiltration trenches.
- Lots may be organized into cluster units separated by open space buffers as long as road networks and driveways are not increased significantly, and the open space tract is not fragmented.
- Place clusters on the site and use native vegetation to screen or buffer higher density clusters from adjacent rural land uses.

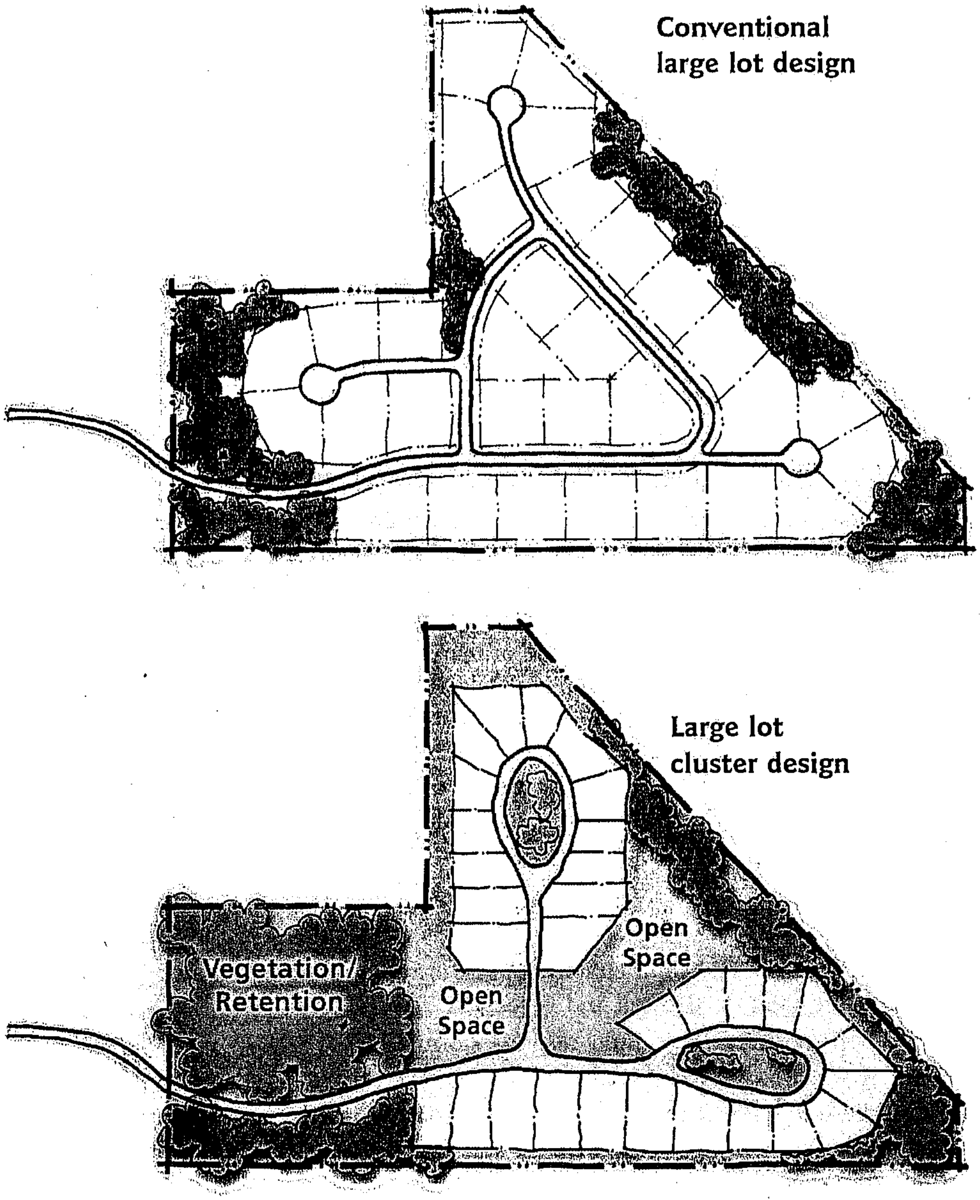


Figure 3.25 Conventional and large lot cluster design

Graphic by AHBL Engineering

3.5 Building Design

Impervious surface associated with roofs ranges from approximately 15 percent for single family residential, 17 percent for multifamily residential, and 26 percent for commercial development (City of Olympia, 1995). As densities increase for detached single-family residential development, opportunities for infiltrating roof stormwater decrease; however, other strategies to process this water can be applied.

Objectives for building design strategies are to disconnect roof stormwater from stormwater conveyance and pond systems (i.e., eliminate roofs as effective impervious surface), and reduce site disturbance from the building footprint. Strategies for minimizing storm flows and disturbance include:

- Reduce building footprint. Designing taller structures can reduce building footprints and associated impervious surface by one-half or more in comparison to a single story configuration. Proposals to construct taller buildings can also

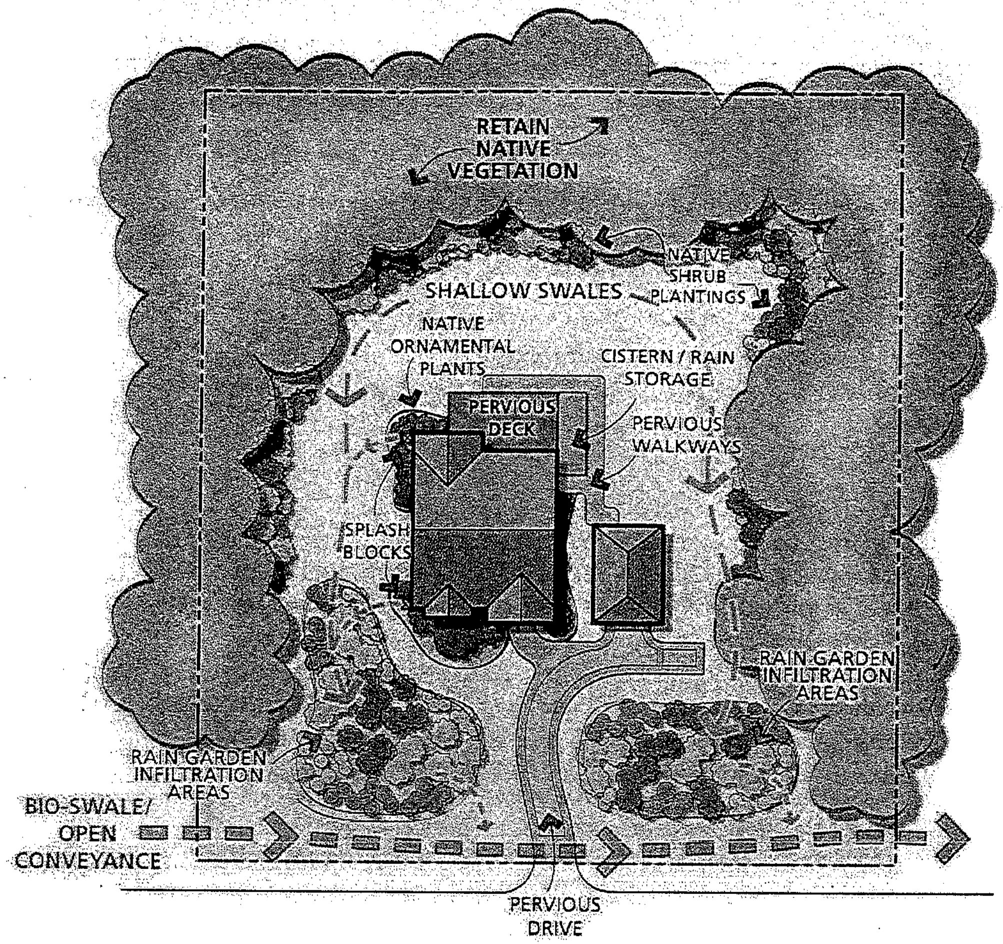


Figure 3.26 Large lot LID design example.

Graphic by AHBL Engineering

present specific fire, safety, and health issues that may need to be addressed. For example, any residence over two stories requires a fire escape and a sprinkler system. These additional costs may be partially reduced by a reduction in stormwater conveyance and pond systems and stormwater utility fees.

- Orient the long axis of the building along topographic contours to reduce cutting and filling.
- Control roof water onsite (see Section 6.4 Vegetated Roofs and Section 6.6 Roof Rainwater Collection Systems for design guidelines).
- Use low impact foundations (see Section 6.5: Minimal Excavation Foundations).
- Limit clearing and grading to road, utility, building pad, landscape areas, and the minimum amount of extra land necessary to maneuver machinery. All other land should be delineated and protected from compaction with construction fencing. (see Chapter 4: Vegetation Protection, Reforestation, and Maintenance, and Chapter 5: Clearing and Grading).

LID in Green Cove Basin

The city of Olympia is using low impact development strategies and other environmental protection measures to preserve high quality forest and aquatic resources in Green Cove basin. One measure includes setting a maximum total impervious surface coverage of 2,500 square feet per lot (Title 18 Unified Development Code: Article II. Land Use Districts).

4 Vegetation Protection, Reforestation, and Maintenance

IN THIS CHAPTER...

- *Native vegetation protection*
- *Reforestation:*
  Plant evaluation and selection
  Plantings
- *Maintenance*

Mature native vegetation and soil are necessary to maintain watershed hydrology, stable stream channels, wetland hydroperiods, and healthy aquatic systems (Booth et al., 2002). While necessary to maintain aquatic systems, native vegetation and soils are also the most cost-effective and efficient tools for managing stormwater quantity and quality. Hydrologic modeling comparing conventional development and low impact development (LID) designs suggests that of the various LID applications, reducing the development envelope and increasing vegetation and soil conservation areas can provide the single largest reduction of storm flows (Table 4.1) (AHBL, 2002).

Table 4.1 Hydrologic modeling comparing a conventional development and the flow reduction benefits from individual practices for a low impact development design. The 24-acre till-mantled site in southern Puget Sound has 103 lots and was modeled with the Western Washington Hydrologic Model (adapted from AHBL, 2000).

	Detention storage reduced (ft³)	Detention storage required (ft³)
Conventional development	0	**270,000**
Low impact development		
Reduce development envelope, 24' wide road	- 149,019	
And use bioretention swales and cells	- 40,061	
And use minimal excavation foundations	- 7,432	
And use 20' wide permeable paving road	-29,988	
Total	-226,500	**43,500**

Retaining native soil and vegetation protection areas is a primary objective for low impact development in order to: (1) reduce total impervious surface coverage; (2) provide infiltration areas for overland flows generated in adjacent developed portions of the project; and (3) maintain or more closely mimic the natural hydrologic function of the site. The protection areas provide additional benefits, including critical area and habitat protection, open space corridors for passive recreation, visual buffers, and erosion and sediment control.

While necessary to maintain aquatic systems, native vegetation and soils are also the most cost-effective and efficient tools for managing stormwater quantity and quality.

Objectives for on-site native vegetation coverage:

- Rural and large lot development: 65 percent minimum.
- Medium density (4 to 6 dwelling units per acre): 50 percent minimum.

- High density (more than 6 dwelling units per acre): protect or restore to the greatest extent practical. Note: in medium to high density settings, reducing the development envelope and protecting native forest and soil areas will often require multifamily, condominium, cottage or mixed attached and detached single family homes (see Chapter 3: Site Planning and Layout).
- Riparian Management Areas can be included as a part of the native vegetation retention area and are the highest priority for native vegetation retention.

The 65 percent forest retention objective is a watershed level target based on best available science for maintaining watershed hydrologic functions (Booth et. al, 2002). Not all projects can achieve 65 percent protection at the project site. However, projects attaining 40, 50 or 60 percent native vegetation protection and using a full complement of LID practices still play a critical role in achieving overall watershed protection objectives when part of a larger planning process that strategically conserves riparian and other sensitive resources at a regional scale.

The following sections provide guidelines for native vegetation protection during the construction phase, enhancement or rehabilitation of impacted areas, and strategies for long-term maintenance.

4.1 Native Vegetation Protection

Native vegetation and soil protection areas in today's urban, suburban, and rural settings are fragments of pre-European contact forests and prairie. Natural successional forces have been altered and active management is required to compensate for the loss of natural processes and the addition of new stressors (Matheny and Clark, 1998). Vegetation protection areas not directly adjacent to structures (or located where they may potentially impact a structure) should be managed to encourage natural successional patterns and develop diverse multilayer canopy structure, snags, large woody debris, understory vegetation, and forest duff. The protection, reforestation, and management strategies provided below are designed to maintain vegetation cover, adequate soil building, and plant regeneration processes necessary for retaining these areas for the long term.

Assessment of natural resources and the site planning process will identify and delineate critical areas and native vegetation offering the best suite of benefits, including greatest infiltration potential. The final delineation and details of the management program for the vegetation protection areas requires assessment by a qualified urban forester or landscape architect that considers size of the area, type of soil, exposure, vegetation type and structure, invasive species impacts, human use, condition of existing vegetation, and existing and post-development hydrologic patterns in the area.

Selection of dispersed individual trees and tracks of native vegetation may be necessary to meet native forest and soil protection objectives. Individual trees selected for protection should have developed as individuals with well-tapered trunks and good live crown ratios (total tree height in relation to the height of the live crown). Trees from dense stands with tall, poorly tapered trunks and high irregular shaped crowns generally do not adapt to wind and sun exposure and are not good candidates to preserve as single trees (Figure 4.1) (Matheny and Clark, 1998). As a general guideline, conifers with live crown ratios of less than 30 percent tend to break in winds while trees with ratios greater than 50 percent tend to be more stable (Matheny and Clark, 1998).

LID in Green Cove Basin

To protect sensitive aquatic resources, the city of Olympia requires all development in the Green Cove basin to have approximately 55 percent tree cover.

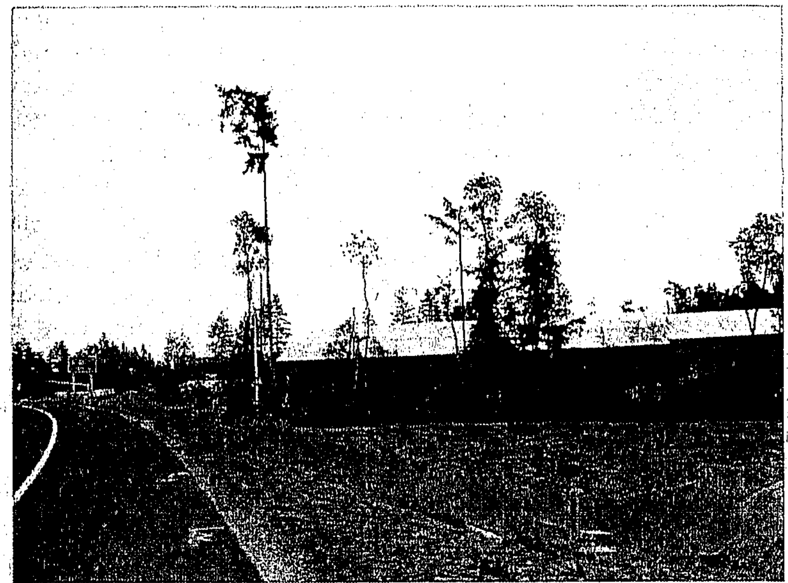


Figure 4.1 These native trees that were retained during clearing have low live crown ratios.
Photo by Curtis Hinman

Trees and other native vegetation that developed in forests or woodlands are best retained in groups of sufficient size to maintain adequate growing space characteristics and the integrity of the unit. Growing space characteristics include soil moisture, sunlight, humidity, wind, competition among adjacent plants, and other growth factors. Retaining small fragments of mature, single species trees adapted to the interior of a forest stand is seldom successful (Matheny and Clark, 1998). Additional stressors along newly exposed edges of larger preserved vegetation tracts can affect unit integrity and result in high initial plant mortality on the perimeter. Replacement of unhealthy trees and other vegetation with material adapted to edge environments, as well as invasive species control, may be necessary (Matheny and Clark, 1998).

Delineation and management of larger tracts and smaller scale, dispersed protection areas are necessary to meet retention objectives on most sites. Larger contiguous tracts are more likely to sustain healthy soils, retain diverse and dense vegetation coverage, and have less area affected by edge stress factors (increased sunlight, wind, and invasive species). Small-scale dispersed protection areas can be located to intercept storm flows at the source, reduce flow volumes within small contributing areas, and maintain time of concentration. Specific site and design requirements will influence the type and distribution of protection areas; however, the location and type of area can influence the extent of benefit and long-term viability.

The following provides a list of native vegetation and soil protection areas prioritized by location and type of area:

1. Large tracts of riparian areas that connect and create contiguous riparian protection areas.
2. Large tracts of critical and wildlife habitat area that connect and create contiguous protection areas.
3. Tracts that create common open space areas among and/or within developed sites.
4. Protection areas on individual lots that connect to areas on adjacent lots or common protection areas.
5. Protection areas on individual lots.

4.1.1 Protection During the Construction Phase

Soil compaction is a leading cause of death or decline of mature trees in developed areas (World Forestry Center, 1989). Most tree roots are located within 3 feet of the ground surface and the majority of the fine roots active in water and nutrient absorption are within 18 inches. Root systems can extend 2 to 3 times beyond the diameter of the crown (World Forestry Center and Morgan, 1993 and Matheny and Clark, 1998). Equipment activity on construction sites can severely compact soil, essentially eliminating soil pore structure at 6 to 8 inches below the ground surface. Compaction can extend as deep as 3 feet depending on soil type, soil moisture, and total axle load of the equipment. Foot traffic can exert per unit area pressure similar to that of a vehicle and significantly compact soil as well (Corish, 1995 and World Forestry Center and Morgan, 1989). Soil compaction results in a reduction of soil oxygen and an increase in **soil bulk density**. In response to soil compaction, tree root penetration, root respiration, and associated uptake of nutrients and minerals decline, **mycorrhizal** activity is reduced, and susceptibility to root disease increases (Matheny and Clark, 1998).

Soil compaction is a leading cause of death or decline of mature trees in developed areas.

Several other direct and indirect impacts can influence vegetation health during land development including:

- Direct loss of roots from trenching, foundation construction, and other grade changes.
- Application of fill material that can compact soil, reduce oxygen levels in existing grade, and change soil chemistry.
- Damage to trunks or branches from construction equipment and activities.
- Exposure of forest interior areas to new stresses of forest edges as land is cleared.
- Changes in surface and subsurface water flow patterns.

Detrimental impacts to native vegetation and soil protection areas can be minimized through the following strategies:

- Map native soil and vegetation protection areas on all plans and delineate these areas on the site with appropriate fencing to protect soils and vegetation from construction damage. Fencing for forest protection areas should be located at a minimum of 3 feet beyond the existing tree canopy along the outer edge of the tree stand. Fencing should provide a strong physical and visual barrier of high strength plastic or metal and be a minimum of 3 to 4 feet high (see Ecology 2005 SMMWW BMP C103 and C104). Silt fencing, or preferably a compost berm, is necessary in addition to, or incorporated with, the barrier for erosion control.
- Install signs to identify and explain the use and management of the natural resource protection areas.
- Meet and walk property with equipment operators to clarify construction boundaries and limits of disturbance.
- Protect drainage areas during construction. Channel or drainage swales that provide a hydrologic connection to vegetation protection area(s) should be protected throughout the construction phase by fencing and erosion control measures to prevent untreated construction site runoff from entering the channel.

- Protect trees and tree root systems utilizing the following methods:
  - Minimize soil compaction by protecting critical tree root zones. The network of shallow tree roots, active in nutrient and water uptake, extends beyond the **tree canopy dripline.** Several methods can be used to assess the area necessary to protect tree roots. The dripline method may be applicable for broad-canopy trees; however, this method will likely underestimate the extent of roots and lead to extensive root damage for narrow-canopied trees and leaning trees with canopies extending to one side more than the other. As a general guideline, the trunk diameter method provides more design flexibility for variable growth patterns. This method provides a protection area with a 1-foot radius for every 1 inch of trunk diameter at chest height (DBH ~ 4.5ft). Factors that influence the specific distance calculated include the tree's tolerance to disturbance, age, and vigor (Matheny and Clark, 1998).
  - Limit to an absolute minimum any excavation within the critical root zone. Tree species and soils will influence the ability of a tree to withstand disturbance. If the tree(s) are to be preserved and excavation in the critical root zone is unavoidable, consult a certified arborist for recommendations.
  - Prohibit the stockpiling or disposal of excavated or construction materials in the vegetation retention areas to prevent contaminants from damaging vegetation and soils.
  - Avoid excavation or changing the grade near trees that have been designated for protection. If the grade level around a tree is to be raised, a retaining wall (preferably with a discontinuous foundation to minimize excavation) should be constructed around the tree. The diameter of the wall should be at least equal to the diameter of the tree canopy plus five feet. If fill is not structural, compact soil to a minimum (usually 85 percent proctor) (World Forestry Center and Morgan, 1993). Some trees can tolerate limited fill if proper soils and application methods are used. Subsoil irrigation may be required. Consult a certified arborist for recommendations.
  - Tree root systems tend to tangle and fuse among adjacent trees. Trees or woody vegetation that will be removed and that are next to preserved trees should be cut rather than pushed over with equipment (World Forestry Center and Morgan, 1993). Stumps can be ground if necessary.
  - Restrict trenching in critical tree root zone areas. Consider boring under or digging a shallow trench through the roots with an air spade if trenching is unavoidable.
  - Prevent wounds to tree trunks and limbs during the construction phase.
  - Prohibit the installation of impervious surfaces in critical root zone areas. Where road or sidewalk surfaces are needed under a tree canopy, non-mortared porous pavers or flagstone (rather than concrete or asphalt) or bridging techniques should be used.
  - Prepare tree conservation areas to better withstand the stresses of the construction phase by watering, fertilizing, pruning, and mulching around them well in advance of construction activities.

4.2 Reforestation

Soil and vegetation protection areas that have been disturbed and do not have vegetation of sufficient size, quantity, and quality to achieve the necessary coverage may require soil enhancement and replanting with native trees and vegetation in order to achieve the full hydrologic benefits of the site (see Section 6.2: Amending Construction Site Soils for soil guidelines). Consult with a qualified urban forester or landscape architect to develop a long-term vegetation and soil management plan.

4.2.1 Existing Plant Evaluation and Site Preparation

Trees remaining in the protection area should have the following characteristics:

- No major pest or pathological problems.
- No extensive crown damage.
- No weakly attached co-dominant trunks if located in areas where failure could cause damage or safety problems.
- Relatively sound trunks without extensive decay or damage.
- Wind-firm in the post development condition.

(Matheny and Clark, 1998).

Trees identified as having significant wildlife value such as snags and nesting sites should be retained regardless of the health of the tree, unless the tree poses an imminent safety threat as determined by a qualified arborist or urban forester (Pierce County Ordinance No 2003-66, 18H.40.040, Tree Conservation Standards).

Intensive inventories and individual tree health evaluation is generally limited to areas where trees can damage existing or proposed structures. Depending on the physical setting, regulatory requirements, aesthetics, and other specific management needs, inventories and subsequent evaluations may be necessary in portions or all of the protection area's interior. If inventories and management plans indicate deficiencies in protected area vegetation structure, removing unhealthy trees may be desirable to free growing space, encourage new seedlings and create age and species diversity. The site should be prepared for planting by removing invasive species, stabilizing erosion areas, and enhancing soil with compost amendment where necessary.

4.2.2 Plant Selection

The native vegetation species should be selected based on the underlying soils and the historic, native indigenous plant community type for the site (Pierce County Ordinance No 2003-66, Exhibit B, Chapter 10, Low Impact Development). Coniferous trees provide greater interception, storage, and evaporation potential in the wet months and should be the major component of the protection area if ecologically compatible with the site. A single species of vegetation should not be used for replacement purposes.

Coniferous trees provide greater interception, storage, and evaporation potential in the wet months and should be the major component of the protection area if ecologically compatible with the site.

The following general guidelines are recommended for installing a self-sustaining native plant community that is compatible with the site and minimizes long-term maintenance requirements:

- The plantings should provide a multilayer canopy structure of large trees, small trees, and shrubs.
- Emphasize climax species, for example Douglas fir (*psuedotsuga menziesii*), on drier sites with more sun exposure, and western red cedar (*thuja plicata*),

western hemlock *(tsuga heterophylla)*, or sitka spruce (*picea sitchensis*) on wetter sites with less sun exposure.

- For many sites, a ratio of 2 evergreens to 1 deciduous tree will provide a mix similar to native forests.
- To create a multilayer canopy, install 50 percent large structure trees to 50 percent small trees and shrubs.
- Space large trees at 15 to 20 feet and shrubs at 4 feet on center.
- The installation should be designed to develop to a dense closed canopy (when compatible with the site) to provide interception and evaporation of precipitation in the wet months and shade the site to exclude invasive vegetation species.

(Personal communication, Bill Barnes August, 2004)

Plants should conform to the standards of the current edition of *American Standard for Nursery Stock* as approved by the American Standards Institute, Inc. All plant grades should be those established in the current edition of *American Standards for Nursery Stock* (current edition: ANSI Z60.1-2004). All plant materials for installation should:

- Have normal, well-developed branches and a vigorous root system.
- Be healthy and free from physical defects, diseases, and insect pests.
- Not have weakly attached co-dominant trunks.

4.2.3 Plant Size

Selecting the optimum size of plant material for installation includes several factors. In general, small plant material requires less careful handling, less initial irrigation, experiences less transplant shock, is less expensive, adapts more quickly to a site, and transplants more successfully than larger material (Sound Native Plants, 2000). Smaller plant material is, however, more easily overgrown by weeds and invasive species such as reed canary grass, is more susceptible to browse damage, and is more easily damaged by maintenance personnel or landowners (Kantz, 2002). Accordingly, the following recommendations are provided:

- Where invasive species are not well established, weeds and browsing are controlled regularly, and maintenance personnel and landowners are trained in proper maintenance procedures, smaller material will likely have a lower mortality rate, is less expensive, and is recommended. Small trees and shrubs are generally supplied in pots of 3 gallons or less.
- Where invasive species are prevalent and weed and browse control is not ensured, larger plant material is recommended. Larger plants will require additional watering during the establishment period.
- For larger tree stock, coniferous and broadleaf evergreen material should be a minimum of 3 feet in height and deciduous trees should have a minimum caliper size of 1 inch (Kantz, 2002).

Native species should be used for vegetation and soil protection areas not adjacent to residential lots or commercial development. Depending on aesthetic needs, cultivars adapted to the region for hardiness may be used in transition areas between protection areas and structures. For growth characteristics and site suitability of trees and shrubs native or adapted to the Pacific Northwest see Appendix 1: Street Trees and Appendix 3: Bioretention Area Plants.

4.2.4 Reference Documents for Planting

Vegetation restoration/planting methods should conform to published standards. The following guidance documents are examples:

- *Restoring the Watershed: A Citizen's Guide to Riparian Restoration in Western Washington,* Washington Department of Fish and Wildlife, 1995.
- *Plant It Right Restoring Our Streams,* Washington State University Extension http://wawater.wsu.edu
- *Integrated Streambank Protection Guidelines*, Washington Department of Fish and Wildlife, 2000.
- *Surface Water and Groundwater on Coastal Bluffs: A Guide for Puget Sound Property Owners*, Washington Department of Ecology, Shorelands and Coastal Zone Management Program Publication No. 95-107, 1995.
- *Vegetation Management: A Guide for Puget Sound Bluff Property Owners*, Washington Department of Ecology, Shorelands and Coastal Zone Management Program Publication No. 93-31, 1993.
- *Relative Success of Transplanted/Outplanted Plants*, Sound Native Plants, 2000.

Plants installed in the fall generally outperform late winter or spring plantings. In fall, the soil is warmer and more aerated than in the spring and transpiration requirements are less than in the spring and summer months. During the fall and winter, plants can develop sufficient root systems, recover from transplant shock, and prepare for the top growth and water demands of the growing season (Sound Native Plants, 2000).

4.3 Maintenance

In a low impact development, native vegetation and soil protection areas serve as stormwater management facilities. Clearly written management plans and protection mechanisms are necessary for maintaining the benefits of these areas over time. Some mechanisms for protection include dedicated tracts, conservation and utility easements, transfer to local land trusts (large areas), and homeowner association covenants. Property owner education should be part of all these strategies.

Ongoing maintenance should include weeding, watering, erosion and sediment control, and replacement of dead plant material for a minimum of three years from installation in order to achieve a minimum 80 percent survival of all plantings. If during the three-year period survival of planted vegetation falls below 80 percent, additional vegetation should be installed to achieve the required survival percentage. Additionally, the likely cause of the plant mortality should be determined (often poor soils and compaction) and corrected. If it is determined that the original plant choices are not well suited to site conditions, these plants should be replaced with plant species better suited to the site.

In a low impact development, native vegetation and soil protection areas serve as stormwater management facilities. Clearly written management plans and protection mechanisms are necessary for maintaining the benefits of these areas over time.

Permanent signs should be installed explaining the purpose of the area, the importance of vegetation and soils for managing stormwater, and that removal of trees or vegetation and compaction of soil is prohibited within the protected area. Permanent fencing, rock barriers, bollards or other access restriction at select locations or around the perimeter of protection areas may be required to limit encroachment.

5 Clearing and Grading

In this chapter...

- *Techniques to minimize site disturbance*

Protecting native soil and vegetation and retaining hydrologic function during the clearing and grading phase presents one of the most significant challenges within the development process. Upper soil layers contain organic material, soil biota, and a structure favorable for storing and slowly conducting stormwater down gradient. Clearing and grading exposes and compacts underlying subsoil, producing a site with significantly different hydrologic characteristics. On till soil, precipitation is rapidly converted to overland flow. Surface and interflow are usually less on sites with native outwash soils and vegetation compared to native till conditions. Accordingly, the increase in overland flow from pre- to post-construction conditions can be greater on outwash than till sites if impervious areas are not minimized and soil structure is not protected for infiltration.

In addition to hydrologic modifications, sediment yield from clearing, grading and other construction activities can significantly affect receiving waters. Gammon found that stream biota was significantly reduced at suspended solids levels of 50 to 80mg/L (Corish, 1995). Schueler reported a median total suspended solids concentration of 4,145 mg/L leaving construction sites without erosion and sediment control and 283 mg/L at sites with controls (the range of concentrations with controls–11 to 2,070 mg/L in the study–was highly variable) (Corish, 1995). Typically, sediment and erosion is managed through structural practices; however, reliance on structural approaches alone to compensate for widespread vegetation loss can add unnecessary construction costs and may not provide adequate protection for aquatic habitat and biota. Minimizing site disturbance as a primary strategy to control erosion reduces the extent of grading, retains vegetation cover, and is the most cost-efficient and effective method for controlling sediment yield (Corish, 1995).

> *Minimizing site disturbance as a primary strategy to control erosion reduces the extent of grading, retains vegetation cover, and is the most cost-efficient and effective method for controlling sediment yield.*

Several factors including topography, hydrology, zoning density and plat design, and housing type influence the timing and extent of clearing and grading activities. The scope of this section does not include the regulatory and market structure influencing clearing and grading, but rather focuses on planning and implementation techniques to reduce impacts to native soils, vegetation, and hydrology on the site.

Proper installation and maintenance of erosion and sediment control **best management practices** (BMPs) are required during the clearing, grading, and construction phases of a project. For detailed guidelines and specifications for erosion and sediment control BMPs see Washington State Department of Ecology 2005 *Stormwater Management Manual for Western Washington* Volume II chapter 4.

5.1 Techniques to Minimize Site Disturbance

Planning and implementation techniques to minimize site disturbance fall into four categories:

- **Site design**
- **Construction planning**
- **Training**
- **Equipment**

5.1.1 Efficient Site Design

- Reduce the overall development envelope and maximize protection of native soils and vegetation with efficient road layout and cluster design (see Chapter 3: Site Planning and Layout).
- Retain natural topographic features that slow and store storm flows.
- Do not increase steep continuous slopes.
- Limit overall project cut and fill through efficient road design and lot layout.
- Minimize cut and fill by orienting the long axis of buildings along contours or staggering floor levels for buildings to adjust to gradient changes.
- Use minimal excavation foundation systems to reduce grading (see Section 6.5 Minimal Excavation Foundations for details).
- Limit clearing and grading disturbance to road, utility, building pad, landscape areas, and the minimum additional area needed to maneuver equipment (a 10-foot perimeter around the building site can provide adequate work space for most activities).
- Limit the construction access to one route if feasible, and locate access where future roads and utility corridors will be placed.

5.1.2 Coordinated Planning and Activities among Construction Entities

- Begin clearing, grading and heavy construction activity during the driest months and conclude by late fall when rainfall and associated soil compaction, erosion, and sediment yield from equipment activity increases. Late fall is also when conditions are most favorable for establishing vegetation.
- Plan efficient sequencing of construction phases to reduce equipment activity and potential damage to soil and vegetation protection areas.
- Establish and maintain erosion and sediment controls before or immediately after clearing and grading activity begins.
- Phase project to complete operations in one section of the site before clearing and grading the next. Project phasing is challenging when coordinating utility, road, and other activities (Corish, 1995). The greatest potential to implement and benefit from phasing will be on large projects where extensive exposed areas are difficult to stabilize over long periods.
- Map native soil and vegetation protection areas on all plans and delineate these areas on the site with appropriate fencing to protect soils and vegetation from clearing, grading, and construction damage. Fencing should provide a strong physical and visual barrier of high strength plastic or metal and be a minimum of 3 to 4 feet high (see Ecology 2005 SMMWW BMP C103 and

C104). Silt fencing, or preferably a compost berm, is necessary in addition to, or incorporated with, the barrier for erosion control.

- Stockpile materials in areas designated for clearing and grading (avoid areas within the development envelope that are designated for bioretention or other bioretention areas).
- Stockpile and reuse excavated topsoil to amend disturbed areas (see Section 6.2: Amending Construction Site Soils for details).
- Small stockpiles of soil should be covered and larger piles seeded for erosion control during wet months.
- Inspections (Corish, 1995):
  - Conduct a pre-construction inspection to determine that adequate barriers have been placed around vegetation protection areas and structural controls are implemented properly.
  - Routine inspections should be conducted to verify that structural controls are maintained and operating effectively throughout construction, and that soil structure and vegetation are maintained within protection areas.
  - Conduct a final inspection to verify that re-vegetated areas are stabilized and that stormwater management systems are in place and functioning properly.

5.1.3 Training Personnel Implementing Project Activities

- Install signs to identify limits of clearing and grading, and explain the use and management of the natural resource protection areas.
- Meet and walk the property with equipment operators regularly to clarify construction boundaries, limits of disturbance, and construction activities.
- Require erosion and sediment control training for operators.

5.1.4 Proper Equipment

Research in the agricultural setting indicates that ground contact pressure generally determines the potential for compaction in the upper 6 to 8 inches of soil while total axle load can influence compaction in the deeper subsoil layers. Vehicles with tracks or tires with axle loads exceeding 10 tons per axle can compact soils as deep as 3 feet (Delong-Hughes, Moncrief, Voorhees and Swan, 2001). A majority of the total soil compaction (70 to 90 percent) can occur in the first pass with equipment (Balousek, 2003).

To minimize the degree and depth of compaction, use equipment with the least ground pressure to accomplish tasks. For smaller projects, many activities can be completed with mini-track loaders that are more precise, require less area to operate, exert less contact pressure than equipment with deep lugged tires, and have lower total axle weight (personal communication, James Lux, August 2004).

6 Integrated Management Practices

In this chapter...

Specifications for:

- *Bioretention areas*
- *Amending construction site soils*
- *Permeable paving*
- *Vegetated roofs*
- *Minimal excavation foundations*
- *Roof rainwater collection systems*

Integrated management practices (IMPs) are the tools used in a low impact development (LID) project for water quality treatment and flow control. The term IMP is used instead of best management practice or BMP (used in a conventional development) because the controls are integrated throughout the project and provide a landscape amenity in the LID design.

6.1 Bioretention Areas

The bioretention concept originated in Prince George's County, Maryland in the early 1990s and is a principal tool for applying the LID design approach. The term bioretention was created to describe an integrated stormwater management practice that uses the chemical, biological, and physical properties of plants, microbes, and soils to remove, or retain, pollutants from stormwater runoff. Numerous designs have evolved from the original application; however, there are fundamental design characteristics that define bioretention across various settings.

Bioretention areas (also known as rain gardens) are:

- Shallow landscaped depressions with a designed soil mix and plants adapted to the local climate and soil moisture conditions that receive stormwater from a small contributing area.
- Facilities designed to more closely mimic natural conditions, where healthy soil structure and vegetation promote the infiltration, storage, and slow release of stormwater flows.
- Small-scale, dispersed facilities that are integrated into the site as a landscape amenity.
- An IMP designed as part of a larger LID approach. Bioretention can be used as a stand-alone practice on an individual lot, for example; however, best performance is achieved when integrated with other LID practices.

Bioretention is an integrated stormwater management practice that uses the chemical, biological, and physical properties of plants, microbes, and soils to remove, or retain, pollutants from stormwater.

The term bioretention is used to describe various designs using soil and plant complexes to manage stormwater. The following terminology is used in this manual:

- Bioretention cells: Shallow depressions with a designed planting soil mix and a variety of plant material, including trees, shrubs, grasses, and/or other herbaceous plants. Bioretention cells may or may not have an under-drain and are not designed as a conveyance system.

- Bioretention swales: Incorporate the same design features as bioretention cells; however, bioretention swales are designed as part of a conveyance system and have relatively gentle side slopes and flow depths that are generally less than 12 inches.
- Bio*detention:* A design that uses vegetative barriers arranged in hedgerows across a slope to disperse, infiltrate, and treat stormwater (see sloped biodetention description in this chapter).

The following section outlines various applications and general design guidelines, as well as specifications, for individual bioretention components. Design examples are also included in Appendix 2 to provide designers with a pool of concepts and specifications useful for developing bioretention facilities specific to local needs. This section draws information from numerous sources; however, many of the specifications and guidelines are from extensive work and experience developed in Prince George's County, Maryland and the city of Seattle.

6.1.1 Applications

While the original concept of bioretention focused on stormwater pollutant removal, the practice is also used for water quantity control. Where the surrounding native soils have adequate infiltration rates, bioretention can be used as a retention facility. Under-drain systems can be installed and the facility used to filter pollutants and detain flows that exceed infiltration capacity of the surrounding soil. However, designs utilizing under-drains provide less flow control benefits.

Rain gardens are a landscape amenity and a stormwater control practice that can be applied in various settings, including:

- Individual lots for rooftop, driveway, and other on-lot impervious surface infiltration.
- Shared facilities located in common areas for individual lots.
- Areas within loop roads or cul-de-sacs.
- Landscaped parking lot islands.
- Within right-of-ways along roads (linear bioretention swales and cells).
- Common landscaped areas in apartment complexes or other multifamily housing designs.

Figure 6.1.1 Bioretention area in center of apartment building courtyard, Portland, Oregon.
Photo by Curtis Hinman

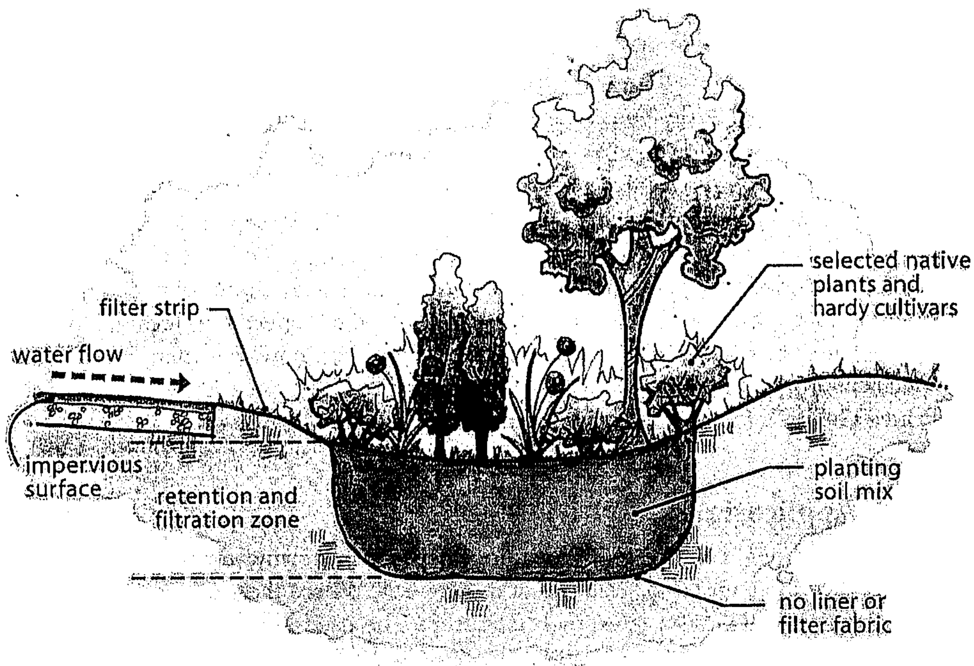


Figure 6.1.2 Cross-section of a basic bioretention cel with no under-drain.

Graphic by AHBL Engineering

6.1.2 Design

Bioretention systems are placed in a variety of residential and commercial settings, and are a visible and accessible component of the site. Design objectives and site context are, therefore, important factors for successful application.

The central design considerations include:

- *Soils:* The soils underlying and surrounding bioretention facilities are a principal design element for determining infiltration capacity, sizing, and rain garden type. The planting soil placed in the cell or swale is highly permeable and high in organic matter (e.g., loamy sand, USDA soil texture classification, mixed thoroughly with compost amendment) and a surface mulch layer. See Section 6.1.2.3: Bioretention Components for details.
- *Site topography:* For slopes greater than 10 percent, sloped biodetention and weep garden designs can be used. See Section 6.1.2.1: Types of bioretention areas.
- *Depth-to-water table:*
  - A minimum separation of 1 foot from the seasonal high water mark to the bottom of the bioretention area is recommended where the contributing area of the bioretention has less than 5,000 square feet of pollution-generating impervious surface; and less than 10,000 square feet of impervious surface; and less than ¾ acres of lawn. Recommended separation distances for bioretention areas with small contributing areas are less than the new Department of Ecology (Ecology) recommendation of 3 feet for two reasons: (1) bioretention soil mixes provide effective pollutant capture; and (2) hydrologic loading and potential for groundwater mounding is reduced when managing flows from small contributing areas.
  - A minimum separation of 3 feet from the seasonal high water mark to the bottom of the bioretention area is recommended where the contributing

area of the bioretention area is equal to or exceeds any of the following limitations: 5,000 square feet of pollution-generating impervious surface; or 10,000 square feet of impervious surface; or ¾ acres of lawn and landscape. See Bioretention Areas in Chapter 7 for flow modeling guidance.

- *Expected pollutant loading:* See sections 6.1.2.3: Bioretention components and 6.1.4: Performance for recommended designs by pollutant type.
- *Site growing characteristics and plant selection:* Appropriate plants should be selected for sun exposure, soil moisture, and adjacent plant communities. Invasive species control may also be necessary.
- *Transportation safety:* The design configuration and selected plant types should provide adequate sight distances, clear spaces, and appropriate setbacks for roadway applications.
- *Visual buffering:* Bioretention facilities can be used to buffer structures from roads, enhance privacy among residences, and for an aesthetic site feature.
- *Ponding depth and surface water draw-down:* Flow control needs, as well as location in the development, will determine draw-down timing. For example, front yards and entrances to residential or commercial developments may require rapid surface dewatering for aesthetics. See Section 6.1.2.3: Bioretention components for details.
- *Impacts of surrounding activities:* Human activity influences the location of the facility in the development. For example, locate bioretention areas away from traveled areas on individual lots to prevent soil compaction and damage to vegetation, and provide barriers to restrict vehicle access in roadside applications.
- *Setbacks:* Local jurisdiction guidelines should be consulted for appropriate bioretention area setbacks from wellheads, on-site sewage systems, basements, foundations, and utilities.

6.1.2.1 Types of bioretention areas

Numerous designs have evolved from the original bioretention concept as designers have adopted the practice to different physical settings. Types of bioretention designs include:

- Bioretention cells integrated into gardens on individual lots.

Figure 6.1.3 Bioretention cell integrated into landscaping.
Photo by Larry Coffman

A007893

- Curb or curbless bioretention in landscaped parking lot islands.

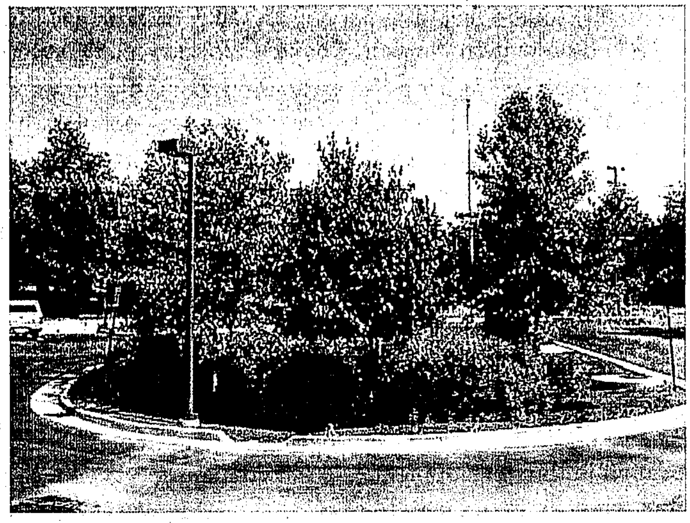


Figure 6.1.4 Bioretention landscaped island with curb cut to allow flows to enter.
Photo by Larry Coffman

- **Off-line bioretention** areas (Figure 6.1.5) are placed next to a swale with a common flow entrance and flow exit, and the bioretention invert placed below the swale **invert** to provide the proper ponding depth (often 6 to 12 inches).

Figure 6.1.5 (left) Off-line bioretention area adjacent to roadside swale.
Photo by Larry Coffman

Figure 6.1.6 (right) Bioretention swale in Seattle.
Photo courtesy of Seattle Public Utilities

- **In-line bioretention** swales are hybrid facilities usually installed along roadways that incorporate bioretention cell and swale characteristics (see Figure 6.1.6 and Appendix 2: Bioretention Examples for design details).

- Sloped or weep garden bioretention areas (Figure 6.1.7) are used for steeper gradients where a retaining wall is used for structural support and for allowing storm flows, directed to the facility, to seep out.

- Sloped biodetention-use vegetative barriers, designed for a specific hydraulic capacity, placed along slope contours (see Figure 6.1.8 and Appendix 2: Bioretention Examples for design details).

Figure 6.1.7 Sloped or steep garden bioretention area.
Photo courtesy of LID Center

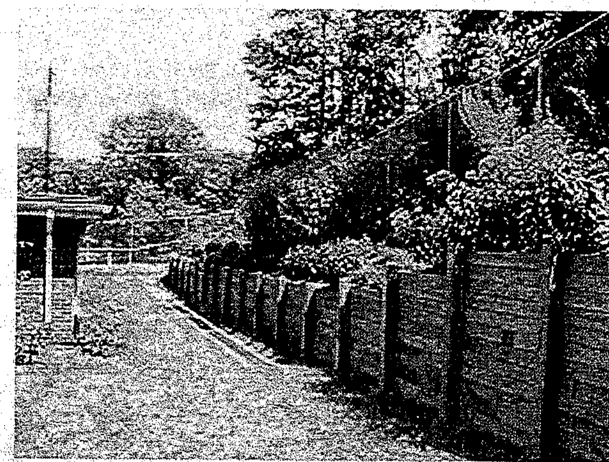
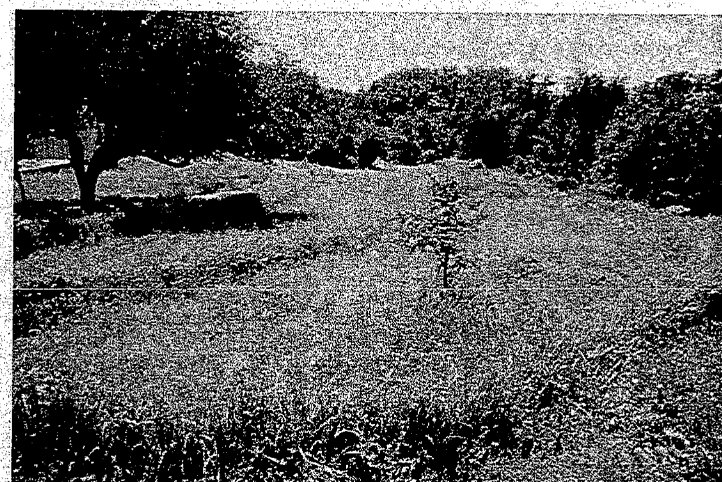


Figure 6.1.8 Sloped biodetention area.
Photo courtesy of Murphee Engineering



- Tree box filters are street tree plantings with an enlarged planting pit for additional storage, a storm flow inlet from the street or sidewalk, and an underdrain system.

Figure 6.1.9 Tree box filter.
Photo by Puget Sound Action Team

6.1.2.2 Determining infiltration rates

Infiltration rates are necessary to determine flow reduction benefits for bioretention areas when using the Western Washington Hydrologic Model (WWHM) or MGS Flood. See Figure 6.1.10 for a graphic representation of the process to determine infiltration rates.

The assumed infiltration rate for determining the flow reduction benefits of bioretention areas should be the lower of the estimated long-term rate of the planting soil mix or the initial (short-termed or measured) infiltration rate of the underlying soil profile. The overlying planting soil mix protects the underlying native soil from sedimentation; accordingly, the underlying soil does not require a correction factor. See Chapter 7 for more detail on flow control modeling for bioretention areas.

The following provides recommended tests for the soils underlying and planting soil mixes within bioretention areas.

1. Underlying native soils:

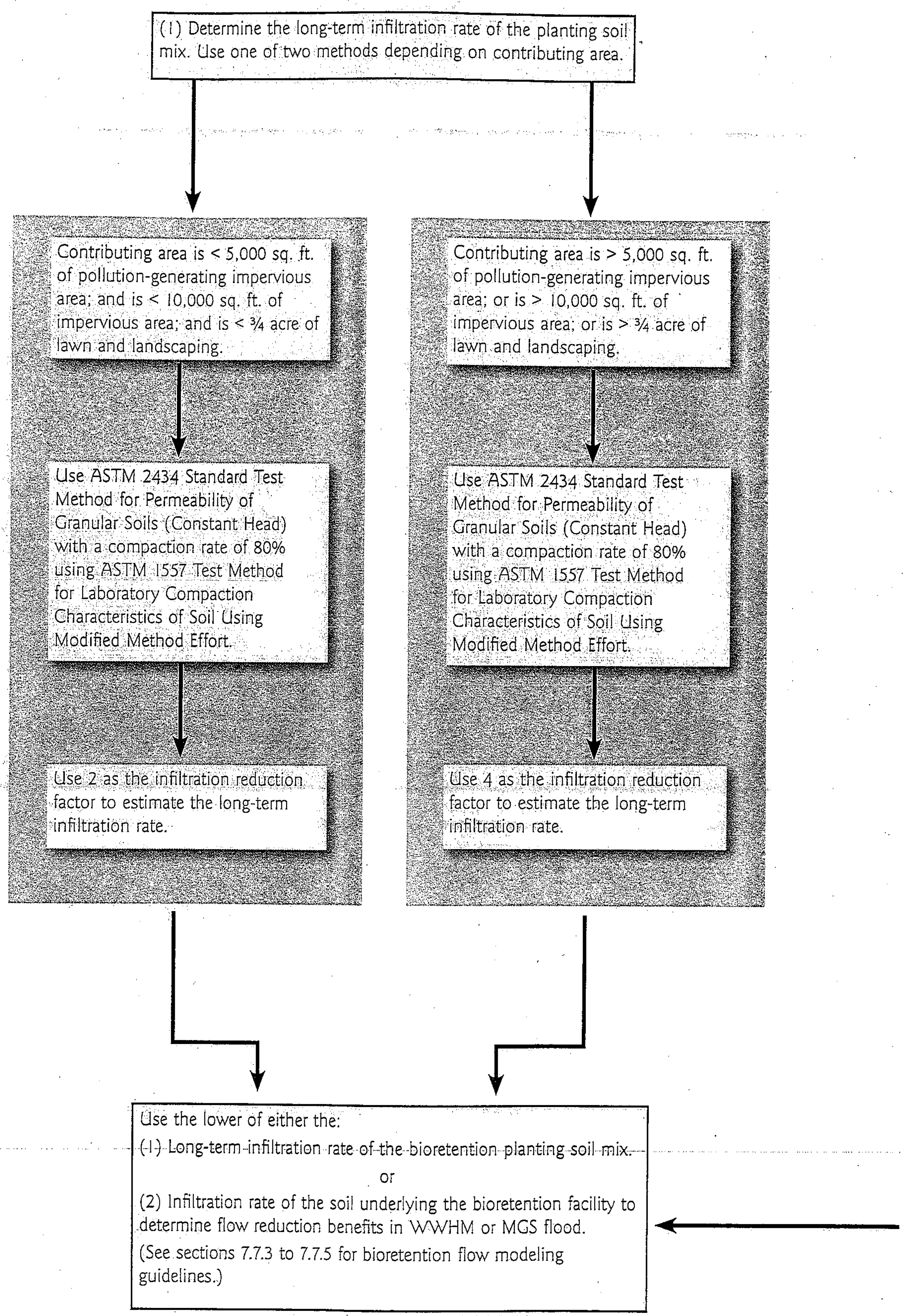
- Method 1: Use Table 3.7 of the Ecology 2005 *Stormwater Management Manual for Western Washington* (SMMWW) to determine the short-term infiltration rate of the underlying soil. Soils not listed in the table cannot use this approach. Use 1 as the infiltration reduction factor.
- Method 2: Determine the D_{10} size of the underlying soil. Use the upperbound line in Figure 4-17 of the Washington State Department of Transportation (WSDOT) 2004 *Highway Runoff Manual* to determine the corresponding infiltration rate. Use 1 as the infiltration reduction factor.
- See the 2005 SMMWW Volume III for details on methods 1 and 2.
- Method 3: Field infiltration tests (the specific test depends on scale of the project).
    - o Small bioretention cells (bioretention facilities receiving water from 1 or 2 individual lots or < 1/4 acre of pavement or other impervious surface): Small-scale infiltration tests such as the U.S. Environmental Protection Agency (USEPA Falling Head or double ring infiltrometer tests, ASTM 3385-88). Small-scale infiltration tests, such as a double ring infiltrometer, may not adequately measure variability of conditions in test areas and, if used, measurements should be taken at several locations within the area of interest. Soil pit excavation may still be necessary if highly variable soil conditions or seasonal high water tables are suspected. Use 1 as an infiltration correction factor.
    - o Large bioretention cells (bioretention facilities receiving water from several lots or 1/4 to 1/2-acre of pavement or other impervious surface): Pilot Infiltration Test (PIT) or small-scale test infiltration pits (septic test pits) at a rate of 1 pit/cell excavated to a depth of at least 5 feet and preferably 6 to 8 feet. See 2005 SMMWW Appendix III-D (formerly V-B) for PIT method description. Use 1 as an infiltration correction factor.
    - o Bioretention swales: approximately 1 pit/50 feet of swale to a depth of at least 5 feet (personal communication, Larry West, Ed O'Brien, 2004).
    - o Consult a geotechnical engineer for site-specific analysis recommendations.
- Use the measured infiltration rate of the underlying native soil as the assumed infiltration rate of the bioretention area if it is lower than the planting soil mix.

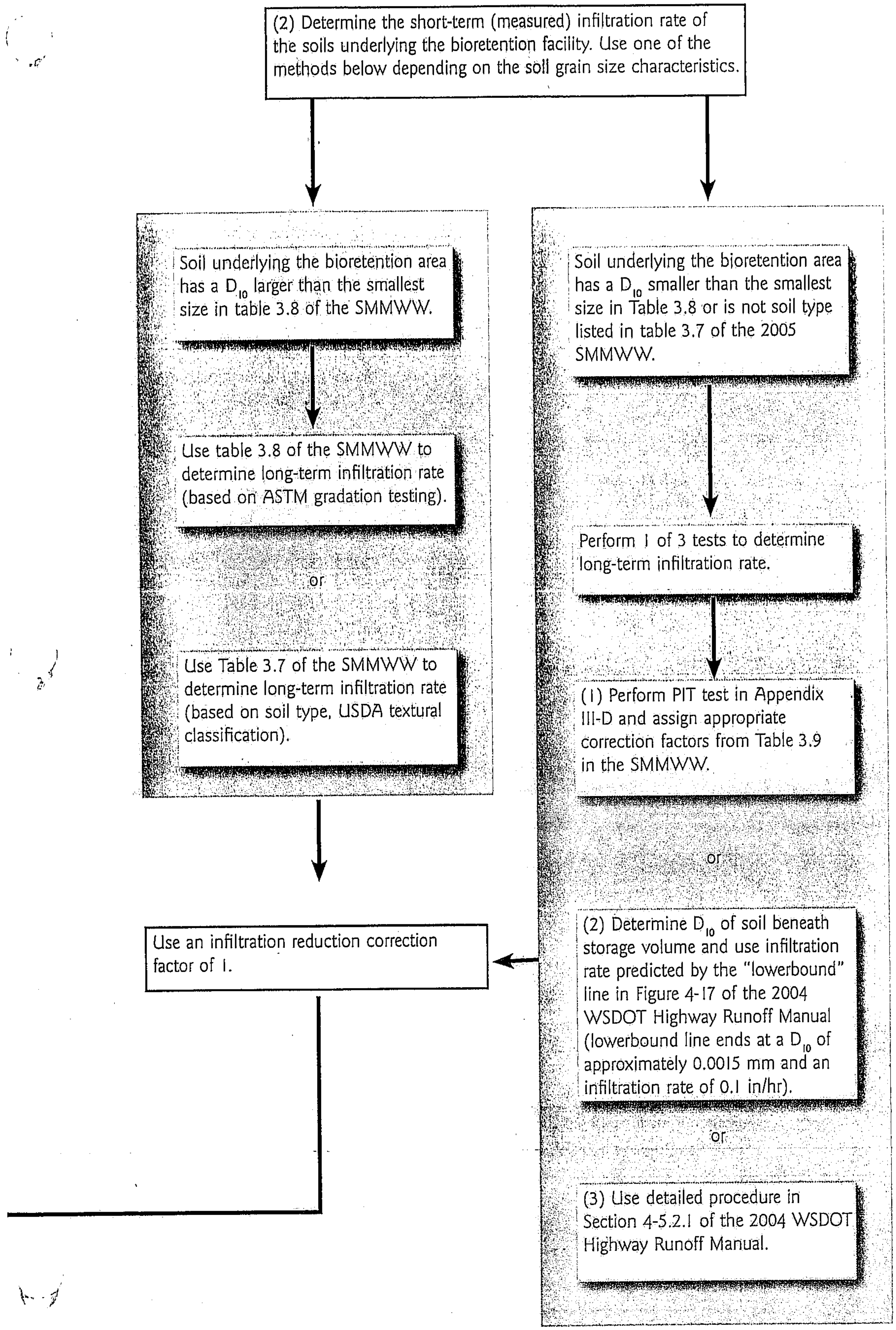
2. Compost-amended planting mix soils: Depending on the size of contributing area use one of the following two recommended test protocols.

Flow Modeling Guidance

See Chapter 7 for guidelines for applying infiltration rates when using the WWHM to determine flow control credits for bioretention areas.

Figure 6.1.10
Recommendations for determining infiltration rates of soils in bioretention areas.
(See sections 7.7.3 to 7.7.5 for using infiltration rates and bioretention flow modeling guidelines.)




(2) Determine the short-term (measured) infiltration rate of the soils underlying the bioretention facility. Use one of the methods below depending on the soil grain size characteristics.
Soil underlying the bioretention area has a D_{10} larger than the smallest size in table 3.8 of the SMMWW.
Use table 3.8 of the SMMWW to determine long-term infiltration rate (based on ASTM gradation testing).
or
Use Table 3.7 of the SMMWW to determine long-term infiltration rate (based on soil type, USDA textural classification).
Soil underlying the bioretention area has a D_{10} smaller than the smallest size in Table 3.8 or is not soil type listed in table 3.7 of the 2005 SMMWW.
Perform 1 of 3 tests to determine long-term infiltration rate.
(1) Perform PIT test in Appendix III-D and assign appropriate correction factors from Table 3.9 in the SMMWW.
or
(2) Determine D_{10} of soil beneath storage volume and use infiltration rate predicted by the "lowerbound" line in Figure 4-17 of the 2004 WSDOT Highway Runoff Manual (lowerbound line ends at a D_{10} of approximately 0.0015 mm and an infiltration rate of 0.1 in/hr).
or
(3) Use detailed procedure in Section 4-5.2.1 of the 2004 WSDOT Highway Runoff Manual.
Use an infiltration reduction correction factor of 1.

- Test 1: If the contributing area of the bioretention cell or swale has less than 5,000 square feet of pollution-generating impervious surface; and less than 10,000 square feet of impervious surface; and less than ¾ acre of lawn and landscape:
  - o Use ASTM D 2434 Standard Test Method for Permeability of granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
  - o Use 2 as the infiltration reduction factor.
- Test 2: If the contributing area of the bioretention cell or swale is equal to or exceeds any of the following limitations: 5,000 square feet of pollution-generating impervious surface; or 10,000 square feet of impervious surface; or ¾ acre of lawn and landscape:
  - o Use ASTM D 2434 Standard Test Method for Permeability of granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
  - o Use 4 as the infiltration reduction factor.
- Use the long-term infiltration rate of the planting soil mix as the assumed infiltration rate of the bioretention area if it is lower than the underlying native soil.

6.1.2.3 Bioretention components

The following provides a description and suggested specifications for the components of bioretention cells and swales. Some or all of the components may be used for a given application depending on the site characteristics and restrictions, pollutant loading, and design objectives. Also see Appendix 2 for various bioretention design examples.

Pretreatment

Vegetated buffer strips slow incoming flows and provide an initial settling of particulates. Design will depend on topography, flow velocities, volume entering the buffer, and site constraints. Flows entering a rain garden should be less than 1.0 ft/second to minimize erosion potential. Engineered flow dissipation (e.g., rock pad) should be incorporated into curb-cut or piped (concentrated) flow entrances.

Flow entrance

Five primary types of flow entrances can be used for bioretention cells:

- *Dispersed, low velocity flow across a landscape area:* This is the preferred method of delivering flows to the rain garden cell. Dispersed flow may not be possible given space limitations or if the facility is controlling roadway or parking lot flows where curbs are mandatory.
- *Dispersed flow across pavement or gravel and past wheel stops for parking areas.*
- *Curb cuts for roadside or parking lot areas:* Curb cuts should include rock or other erosion protection material in the channel entrance to dissipate energy. Flow entrance should drop 2 to 3 inches from curb line and provide an area for settling and periodic removal of sediment and coarse material before flow dissipates to the remainder of the cell (Prince George's County, Maryland, 2002, and U.S. Army Environmental Center and Fort Lewis, 2003).
- *Pipe flow entrance:* Piped entrances should include rock or other erosion protection material in the channel entrance to dissipate energy and/or flow dispersion.

- *Catch basin:* Catch basins can be used to slowly release water to the bioretention area through a grate for filtering coarse material.

Woody plants can restrict or concentrate flows and can be damaged by erosion around the root ball and should not be placed directly in the entrance flow path (Prince George's County, 2002).

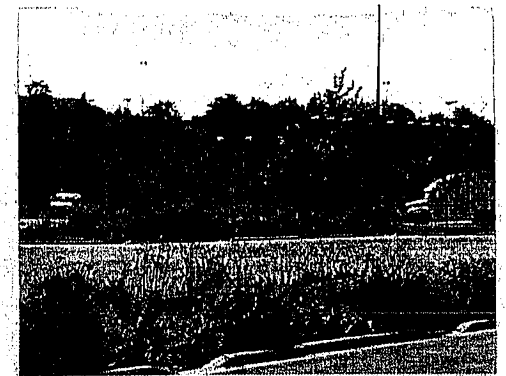


Figure 6.1.11 Bioretention with curb cuts in parking lot islands.
Photo by Larry Coffman

Ponding area

The ponding area provides surface storage for storm flows, particulate settling, and the first stages of pollutant treatment within the cell. Pool depth and draw-down rate are recommended to provide surface storage, adequate infiltration capability, and soil moisture conditions that allow for a range of appropriate plant species (Prince George's County, 2002).

- Maximum ponding depth: 12 inches recommended.
- Surface pool drawdown time: 24 hours recommended.
- Soils must be allowed to dry out periodically in order to:
  - o Restore hydraulic capacity to receive flows from subsequent storms.
  - o Maintain infiltration rates.
  - o Maintain adequate soil oxygen levels for healthy soil biota and vegetation.
  - o Provide proper soil conditions for biodegradation and retention of pollutants. (Ecology, 2001)

Under-drain

The area above an under-drain pipe in a bioretention area provides detention and pollutant filtering; however, only the area below the under-drain invert and the bottom of the bioretention facility can be used in the WWHM for flow control benefit (see Chapter 7 for bioretention area flow control credits). Under-drain systems (see Figure 6.1.12) should be installed only when the bioretention area is:

- Located near sensitive infrastructure (e.g., unsealed basements) and potential for flooding is likely.
- Used for filtering storm flows from gas stations or other pollutant hotspots (requires impermeable liner).
- In soils with infiltration rates that are not adequate to meet maximum pool and system dewater rates.

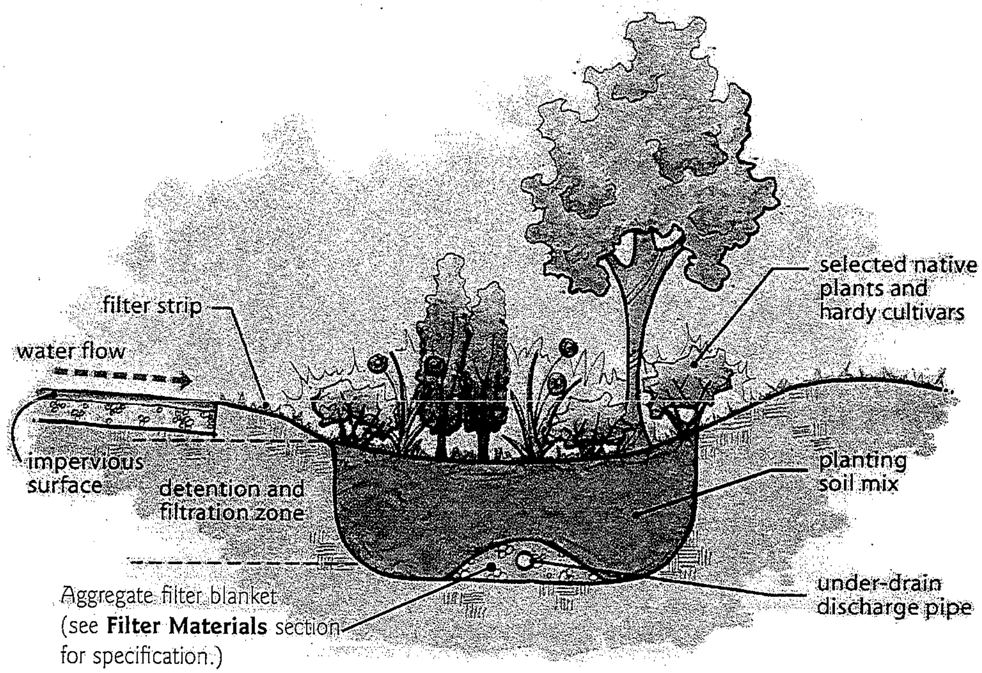
The under-drain can be connected to a downstream open conveyance (bioretention swale), to another bioretention cell as part of a connected treatment system, daylight to a dispersion area using an effective flow dispersion practice, or to a storm drain.

The pipe diameter will depend on hydraulic capacity required (4 to 8 inches is common). The preferred material is slotted 6-inch, thick-walled plastic pipe. The slot opening should be smaller than the smallest aggregate gradation for the gravel blanket to prevent migration of material into the drain. This configuration allows for pressurized water cleaning and root cutting if necessary (personal communication, Tracy Tackett, 2004). Example specification:

- Slotted subsurface drain PVC per ASTM D1785 SCH 40.
- Slots should be cut perpendicular to the long axis of the pipe and be 0.04 to 0.069 inches by 1 inch long and be spaced 0.25 inches apart (spaced longitudinally). Slots should be arranged in four rows spaced on 45-degree centers and cover ½ of the circumference of the pipe. See Filter Materials section for aggregate gradation appropriate for this slot size.

Figure 6.1.12 Bioretention with under-drain.

Graphic by AHBL Engineering



Perforated PVC or flexible slotted HDPE pipe can be used; however, cleaning operations, if necessary, can be more difficult or not possible. Under-drains should be sloped at a minimum of 0.5 percent unless otherwise specified by an engineer (Low Impact Development Center, 2004). Wrapping the under-drain pipe in filter fabric increases chances of clogging and is not recommended (Low Impact Development Center, 2004). A 6-inch rigid non-perforated observation pipe or other maintenance access should be connected to the under-drain every 250 to 300 feet to provide a clean-out port, as well as an observation well to monitor dewatering rates (Prince George's County, 2002 and personal communication, Tracey Tackett, 2004).

Bioretention areas do not effectively remove nitrate. Where nitrate is a concern, the under-drain can be elevated from the bottom of the bioretention facility and within the gravel blanket to create a fluctuating anaerobic/aerobic zone below the drain pipe (Figure 6.1.13). **Denitrification** within the anaerobic zone is facilitated by microbes using forms of nitrogen (NO_2 and NO_3) instead of oxygen for respiration. Adding a suitable carbon source (e.g., wood chips) to the gravel layer provides a nutrition source for the microbes, enables anaerobic respiration, and can enhance the denitrification process (Kim, Seagren and Davis, 2003).

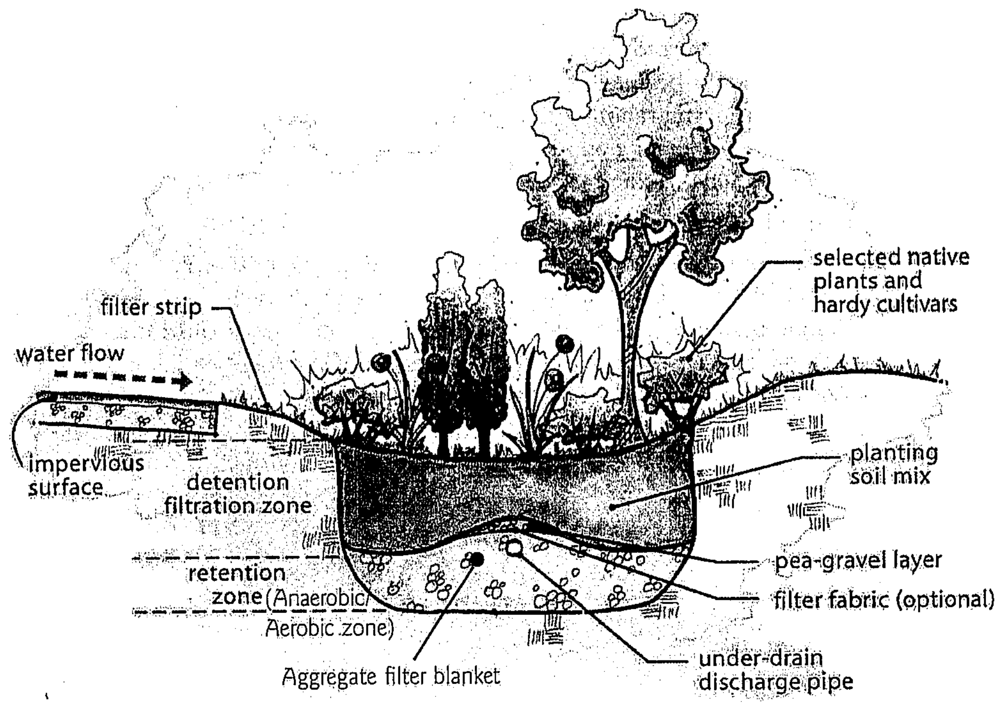


Figure 6.1.13 Bioretention with elevated under-drain.

Graphic by AHBL Engineering

Filter materials

Gravel blankets and filter fabrics buffer the under-drain system from sediment input and clogging. Properly selected for the soil gradation, geosynthetic filter fabrics can provide adequate protection from the migration of fines. Aggregate filter blankets, with proper gradations, provide a larger surface area for protecting under-drains and are preferred.

Suggested specifications for filter materials include:

1. For use with heavy walled slotted pipe (see under-drain specification above):
   - Type 26 mineral aggregate (gravel backfill for drains, city of Seattle)

Sieve size	Percent Passing
¾ inch	100
¼ inch	30-60
US No. 8	20-50
US No. 50	3-12
US No. 200	0-1

   - Place under-drain on a 3-foot wide bed of the Type 26 aggregate at a minimum thickness of 6 inches and cover with Type 26 aggregate to provide a 1-foot minimum depth around the top and sides of the slotted pipe.

2. If proper gradation and/or slotted pipe are not available and perforated PVC or flexible HDPE pipe is used:
   - The under-drain pipe should be placed on a 3-foot wide bed of ½ to 1½-inch drain rock (ASTM No. 57 aggregate or equivalent) at a minimum thickness of 3 inches, and covered with 6 inches of No. 57 aggregate.

Double-washed stone is preferred to reduce suspended solids and potential for clogging (Low Impact Development Center, 2004).

- If filter fabric is used, use a non-woven material placed over the drain rock and extending 2 feet on either side of the under-drain. Wrapping the gravel blanket in filter fabric can cause premature failure due to clogging and is not recommended (Prince George's County, 2002).
- A pea gravel diaphragm (with or without a filter fabric) reduces the likelihood of clogging when used with drain rock. Use ¼ to ½-inch diameter double-washed gravel (ASTM D 448 or equivalent) placed over the drain rock to a thickness of 3 to 8 inches (Prince George's County, 2002). If filter fabric is used, place between the drain rock and pea gravel extending 2 feet on either side of the under-drain. The strip of filter fabric placed above the under-drain acts as an impediment to direct gravitational flow and causes the water to move laterally and then down toward the under-drain (personal communication, Derek Winogradoff, August 2004).

Surface overflow

Surface overflow can be provided by surface drains installed at the designed maximum ponding elevations that are connected to under-drain systems, or by overflow channels connected to downstream surface conveyance, such as bioretention swales and open space areas. Safe discharge points are necessary to convey flows that exceed the capacity of the facility and to protect adjacent natural site features and property.

Hydraulic restriction layers

Adjacent roads, foundations or other infrastructure may require that infiltration pathways are restricted to prevent excessive hydrologic loading. Three types of restricting layers can be incorporated into bioretention designs:

- Filter fabric can be placed along vertical walls to reduce lateral flows.
- Clay (bentonite) liners are low permeability liners. Where clay liners are used under-drain systems are necessary. See 2005 SMMWW Volume IV section 4.4.3 for guidelines.
- Geomembrane liners completely block flow and are used for groundwater protection when bioretention facilities are used for filtering stormflows from pollutant hotspots. Where geomembrane liners are used under-drain systems are necessary. The liner should have a minimum thickness of 30 mils and be ultraviolet (UV) resistant.

Plant materials

Plant roots aid in the physical and chemical bonding of soil particles that is necessary to form stable aggregates, improve soil structure, and increase infiltration capacity. During the wet months in the Pacific Northwest (November through March) interception and evaporation are the predominant above-ground mechanisms for attenuating precipitation in the native forest setting. Transpiration during the non-growing wet months is minimal (see Introduction for details). In a typical bioretention cell, transpiration is negligible unless the cell has a dense planting of trees, the stand is relatively mature (10 to 20 years), and the canopy structure is closing and varied. The relatively mature and dense canopy structure is necessary for adequate interception and advective evaporation in winter months. The primary and significant benefits of small trees, shrubs, and ground cover in bioretention areas during the wet season are the presence of root activity and contribution of organic matter that aids in the development of soil structure and infiltration capacity. See Appendix 3 for a bioretention plant table describing plant characteristics and optimum location within the bioretention area.

The primary design considerations for plant selection include:

- *Soil moisture conditions:* Plants should be tolerant of summer drought, ponding fluctuations, and saturated soil conditions for the lengths of time anticipated by the facility design.
- *Expected pollutant loadings:* Plants should tolerate typical pollutants and loadings from the surrounding land uses.
- *Above and below ground infrastructure in and near the facility:* Plant size and wind firmness should be considered within the context of the surrounding infrastructure. Rooting depths should be selected to not damage underground utilities if present. Slotted or perforated pipe should be more than 5 feet from tree locations (if space allows).
- *Adjacent plant communities and potential invasive species control.*
- *Site distances and setbacks for roadway applications.*
- *Visual buffering:* Plants can be used to buffer structures from roads, enhance privacy among residences, and provide an aesthetic amenity for the site.
- *Aesthetics:* Visually pleasing plant designs add value to the property and encourage community and homeowner acceptance. Homeowner education and participation in plant selection and design for residential projects should be encouraged to promote greater involvement in long-term care.

In general, the predominant plant material utilized in bioretention areas are facultative species adapted to stresses associated with wet and dry conditions (Prince George's County, 2002). Soil moisture conditions will vary within the facility from saturated (bottom of cell) to relatively dry (rim of cell). Accordingly, wetland plants may be used in the lower areas, if saturated soil conditions exist for appropriate periods, and drought-tolerant species planted on the perimeter of the facility or on mounded areas (Figure 6.1.14). See Appendix 3 for recommended plant species.

Planting schemes will vary with the surrounding landscape and design objectives. For example, plant themes can reflect surrounding wooded or prairie areas. Monoculture planting designs are not recommended. As a general guideline, a minimum of three tree, three shrubs, and three herbaceous groundcover species should be incorporated to protect against facility failure due to disease and insect infestations of a single species (Prince George's County, 2002). See Figure 6.1.15 for a sample planting plan.

Native plant species, placed appropriately, tolerate local climate and biological stresses and usually require no nutrient or pesticide application in properly designed soil mixes. Natives can be used as the exclusive material in a rain garden or in combination with hardy cultivars that are not invasive and do not require chemical inputs. In native landscapes, plants are often found in associations that grow together well given specific moisture, sun, soil, and plant chemical interactions. Native plant associations can, in part, help guide planting placement. For example, in partial sun and well-drained soils, beaked hazelnut (*Corylus cornuta*) and common snowberry (*Symphoricarpos albus*) are a common association in western Washington (Leigh, 1999). To increase survival rates and ensure quality of plant material, the following guidelines are suggested:

Figure 6.1.14 Examples of plants appropriate for different soil moisture zones in a bioretention area.

See Appendix 3 for a bioretention plant list organized by soil moisture zones.

Graphic by AHBL Engineering

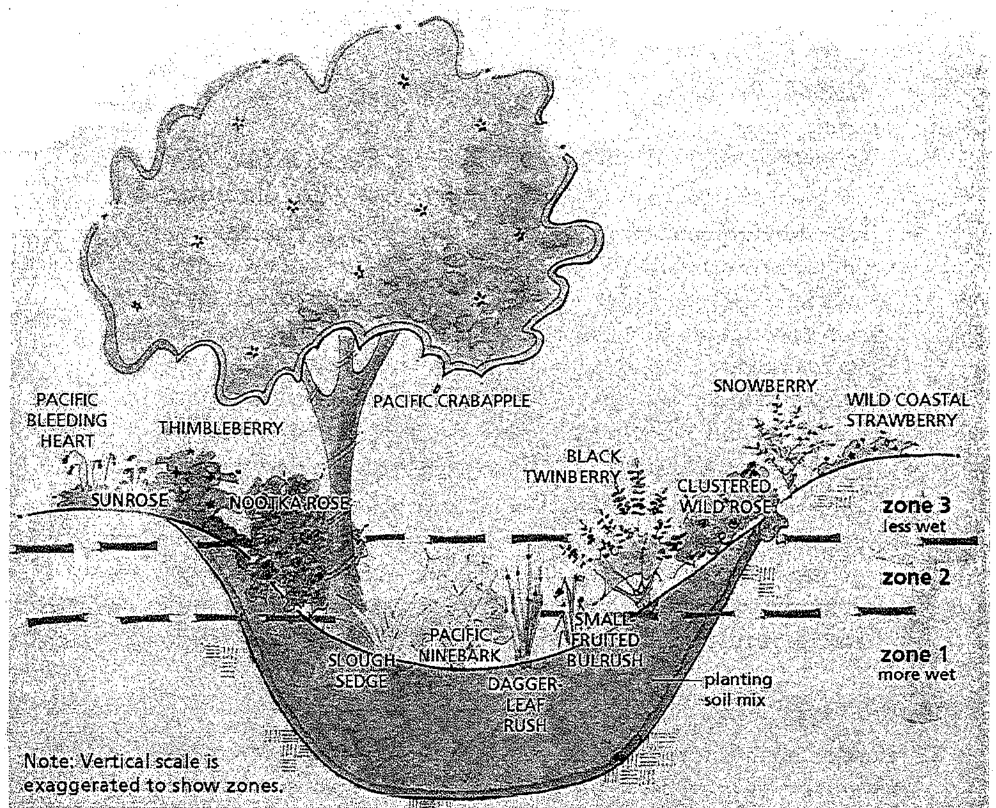
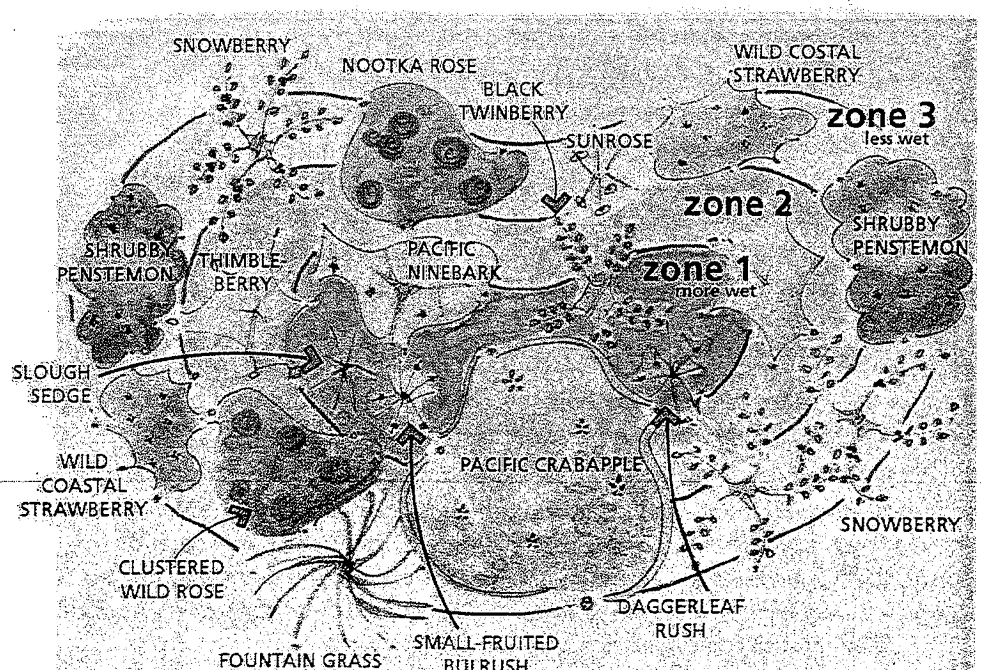


Figure 6.1.15 Sample planting plan for a bioretention area.

Graphic by AHBL Engineering



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- Plants should conform to the standards of the current edition of *American Standard for Nursery Stock* as approved by the American Standards Institute, Inc. All plant grades shall be those established in the current edition of *American Standards for Nursery Stock* (current edition: ANSI Z60.1-2004) (Low Impact Development Center, 2004).
- All plant materials should have normal, well-developed branches and vigorous root systems, and be free from physical defects, plant diseases, and insect pests.
- Plant size: Bioretention areas provide excellent soil conditions and should have well defined maintenance agreements. In this type of environment small plant material provides several advantages and is recommended. Specifically, small plant material requires less careful handling, less initial irrigation, experiences less transplant shock, is less expensive, adapts more quickly to a site, and transplants more successfully than larger material (Sound Native Plants, 2000). Small trees and shrubs are generally supplied in pots of 3 gallons or less.
- All plants should be tagged for identification when delivered.
- Optimum planting time is fall (beginning early October). Winter planting is acceptable; however, extended freezing temperatures shortly after installation can increase plant mortality. Spring is also acceptable, but requires more summer watering than fall plantings. Summer planting is the least desirable and requires regular watering for the dry months immediately following installation.

Mulch layer

Bioretention areas can be designed with or without a mulch layer; however, there are advantages to providing a mulch application or a dense groundcover. Research indicates that most attenuation of heavy metals in bioretention cells occurs in the first 1 to 2 inches of the mulch layer. That layer can be easily removed or added to as part of a standard and periodic landscape maintenance procedure. No indications of special disposal needs are indicated at this time from older bioretention facilities in the eastern U.S. (personal communication, Larry Coffman). Properly selected mulch material also reduces weed establishment, regulates soil temperatures and moisture, and adds organic matter to soil. When used, mulch should be:

- Compost in the bottom of the facilities (compost is less likely to float and is a better source for organic materials) and shredded or chipped hardwood or softwood in surrounding areas.
- Free of weed seeds, soil, roots and other material that is not **bole** or branch wood and bark.
- A maximum of 2 to 3 inches thick (thicker applications can inhibit proper oxygen and carbon dioxide cycling between the soil and atmosphere) (Prince George's County, 2002).

Mulch should **not** be:

- Grass clippings (decomposing grass clippings are a source of nitrogen and are not recommended for mulch in bioretention areas).
- Pure bark (bark is essentially sterile and inhibits plant establishment).

Dense groundcover enhances soil structure from root activity, does not have the tendency to float during heavy rain events, inhibits weed establishment, provides additional aesthetic appeal, and is recommended when heavy metal loading is not anticipated (Prince George's County, 2002). Mulch is recommended in conjunction with the groundcover until groundcover is established.

Soil

Proper soil specification, preparation and installation are the most critical factors for bioretention performance. Soil specifications can vary according to the design objectives. Five different soil specifications are provided in Appendix 2 to illustrate various design approaches. In general, soil designed for bioretention areas should have the following characteristics:

- The texture for the soil component of the bioretention soil mix should be loamy sand (USDA Soil Textural Classification).
- The final soil mix (including compost and soil) should have a minimum long-term hydraulic conductivity of 1.0 inch/hour per ASTM Designation D 2434 (Standard Test Method for Permeability of Granular Soils) at 80 percent compaction per ASTM Designation D 1557 (Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort) (Tackett, 2004). Infiltration rate and hydraulic conductivity are assumed to be approximately the same in a uniform mix soil.
- The final soil mixture should have a minimum organic content of 10 percent by dry weight per ASTM Designation D 2974 (Standard Test Method for Moisture, Ash and Organic Matter of Peat and Other Organic Soils) (Tackett, 2004). Currently, gravelly sand bioretention soil mixtures for bioretention areas are being developed and installed to provide adequate infiltration rates at 85 to 95 percent compaction. While designers anticipate good performance from this specification, the mix may be slightly less than optimal for plant growth and has not been tested long-term for plant health performance (see Engineered Soil Mix and Bioretention Soil Mix 2 and 3 in Appendix 2).
- Achieving the above recommendations will depend on the specific soil and compost characteristics. In general, the recommendation can be achieved with 60 to 65 percent loamy sand mixed with 35 to 40 percent compost or 30 percent sandy loam, 30 percent course sand, and 40 percent compost.
- The final soil mixture should be tested by an independent laboratory prior to installation for fertility, micronutrient analysis, and organic material content. Soil amendments per laboratory recommendations (if any) should be uniformly incorporated for optimum plant establishment and early growth (Tackett, 2004).
- Clay content for the final soil mix should be less than 5 percent.
- The pH for the soil mix should be between 5.5 and 7.0 (Stenn, 2003). If the pH falls outside of the acceptable range, it may be modified with lime to increase the pH or iron sulfate plus sulfur to lower the pH. The lime or iron sulfate must be mixed uniformly into the soil prior to use in bioretention area (Low Impact Development Center, 2004).
- Soil depth should be a minimum of 18 inches to provide acceptable minimum pollutant attenuation and good growing conditions for selected plants. A minimum depth of 24 inches should be selected for improved phosphorus and nitrogen (TKN and ammonia) removal. Deeper soil profiles (> 24 inches) can enhance phosphorus, TKN and ammonia removal (Davis, Shokouhian, Sharma and Minami, 1998). Nitrate removal in bioretention cells can be poor and in some cases cells can generate nitrate due to nitrification (Kim et al., 2003). See under-drain section for design recommendations to enhance nitrate removal. Deeper or shallower profiles may be desirable for specific plant, soil, and storm flow management objectives.
- The soil mix should be uniform and free of stones, stumps, roots or other similar material > 2 inches.

Organic matter content of soil mixes

A quick way to determine the approximate organic matter content of a soil mix:

- Compost is typically 40-50% organic matter (use 50% as an average).
- Compost weighs approximately 50% as much as loam.
- A mix that is 40% compost measured by volume is roughly 20% organic matter by volume.
- Compost is only 50% as dense as the soil, so the mix is approximately 10% organic matter by weight (the organic matter content in soil is determined by weighing the organic material before combustion and then weighing the ash post-combustion).

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- To reduce transportation and disposal needs, on-site excavated soil, rather than imported soil, can be used. However, using on-site excavated soil for the amended soil mix may reduce control over gradation, organic content, and final product performance, can increase project costs, and can complicate construction logistics when attempting to blend soil mix components in restricted space or during winter months (personal communication, Tracy Tackett). If on-site excavated soil is used, representative samples should be tested for gradation and adjusted, if necessary, to attain adequate infiltration capability.
- The above guidelines should provide a soil texture, organic content, and infiltration rate suitable to meet Ecology's SSC-6 "Soil Physical and Chemical Suitability for Treatment" recommendations for designing infiltration systems. A soils report evaluating these parameters should be provided to verify the treatment capability of the soil mix.

Compost

See Section 6.2.2 for compost specifications.

6.1.2.4 Installation

Excavation

Soil compaction can lead to facility failure; accordingly, minimizing compaction of the base and sidewalls of the bioretention area is critical (Prince George's County, 2002). Excavation should not be allowed during wet or saturated conditions. Excavation should be performed by machinery operating adjacent to the bioretention facility and no heavy equipment with narrow tracks, narrow tires, or large lugged, high pressure tires should be allowed on the bottom of the bioretention facility (Tackett, 2004). If machinery must operate in the bioretention cell for excavation, use light weight, low ground-contact pressure equipment and rip the base at completion to refracture soil to a minimum of 12 inches (Prince George's County, 2002).

Sidewalls of the facility, to the height of the grade established by the designed soil mix, can be vertical if soil stability is adequate. Exposed sidewalls should be no steeper than 3H:1V. The sidewalls and bottom should be roughened where scraped and sealed by excavation equipment (Prince George's County, 2002). The bottom of the facility should be flat.

Vegetation protection areas with intact native soil and vegetation should not be cleared and excavated for bioretention facilities.

Soil installation

On-site soil mixing or placement should not be performed if soil is saturated. The bioretention soil mixture should be placed and graded by excavators and/or backhoes operating adjacent to the bioretention facility. If machinery must operate in the bioretention cell for soil placement or soil grading, use light weight, low ground-contact pressure equipment. The soil mixture should be placed in horizontal layers not to exceed 12 inches per lift for the entire area of the bioretention facility.

The soil mixture will settle and proper compaction can be achieved by allowing time for natural compaction and settlement. To speed settling, each lift can be watered until just saturated. Water for saturation should be applied by spraying or sprinkling.

An appropriate sediment control device should be used to treat any sediment-laden water discharged from an under-drain (Low Impact Development Center, 2004).

Sediment Control

Erosion and sediment problems are most difficult during clearing, grading, and construction; accordingly, minimizing site disturbance to the greatest extent practicable is the most effective sediment control. Bioretention facilities should not be used as sediment control facilities and all drainage should be directed away from bioretention facilities after initial rough grading. Flow can be directed away from the facility with temporary diversion swales or other approved protection (Prince George's County, 2002). Bioretention facilities should not be constructed until all contributing drainage areas are stabilized according to erosion and sediment control BMPs and to the satisfaction of the engineer. Erosion and sediment control practices must be inspected and maintained on a regular basis. If deposition of fines occurs in the bioretention area, material should be removed and the surface scarified to the satisfaction of the project engineer (Prince George's County, 2002).

6.1.3 Maintenance

Bioretention areas require annual plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant removal capabilities. In general, bioretention maintenance requirements are typical landscape care procedures and include:

- *Watering:* Plants should be selected to be drought tolerant and not require watering after establishment (2 to 3 years). Watering may be required during prolonged dry periods after plants are established.
- *Erosion control:* Inspect flow entrances, ponding area, and surface overflow areas periodically, and replace soil, plant material, and/or mulch layer in areas if erosion has occurred. Properly designed facilities with appropriate flow velocities should not have erosion problems except perhaps in extreme events. If erosion problems occur the following should be reassessed: (1) flow volumes from contributing areas and bioretention cell sizing; (2) flow velocities and gradients within the cell; and (3) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioretention area, immediately determine the source within the contributing area, stabilize, and remove excess surface deposits.
- *Plant material:* Depending on aesthetic requirements, occasional pruning and removing dead plant material may be necessary. Replace all dead plants and if specific plants have a high mortality rate, assess the cause and replace with appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule should become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants excluded.
- *Nutrient and pesticides:* The soil mix and plants are selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and may degrade the pollutant processing capability of the bioretention area, as well as contribute pollutant loads to receiving waters.
- By design, bioretention facilities are located in areas where phosphorous and nitrogen levels are often elevated and these should not be limiting nutrients. If in question, have soil analyzed for fertility.

- *Mulch:* Replace mulch annually in bioretention facilities where heavy metal deposition is likely (e.g., contributing areas that include parking lots and roads). In residential lots or other areas where metal deposition is not a concern, replace or add mulch as needed to maintain a 2 to 3 inch depth at least once every two years.
- *Soil:* Soil mixes for bioretention facilities are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in bioretention systems (see Performance section below). Replacing mulch in bioretention facilities where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have soil analyzed for fertility and pollutant levels.

6.1.4 Performance

Pollutant removal processes in bioretention

All primary pathways for removing pollutants from storm flows are active in bioretention systems. Schueler and Clayton (1996) list the following as the primary pathways:

- *Sedimentation* is the settling of particulates (not effective for removing soluble components). Sedimentation occurs in the pretreatment (if provided) and ponding area of the facility.
- *Filtration* is the physical straining of particulates (not an effective mechanism for removing soluble components). Some filtration occurs in the ponding area as stormwater moves through plants, but the soil is the primary filtering media. Pitt et al., (1995) report that 90 percent of small particles commonly found in urban storm flows (6 to 41 microns) can be trapped by an 18-inch layer of sand. This level of performance can be anticipated for bioretention soils typically high in sand content.
- *Adsorption* is the binding of ions and molecules to electrostatic receptor sites on the filter media particles. This is the primary mechanism for removing soluble nutrients, metals, and organics that occur in the soil of bioretention areas as storm flows infiltrate. Adsorption increases with increased organic matter, clay, and a neutral to slightly alkaline pH.
- *Infiltration* is the downward movement of surface water to interstitial soil water. This process initiates adsorption, microbial action, etc., for pollutant removal.
- *Phytoremediation* processes include degradation, extraction by the plant, containment within the plant (assimilation) or a combination of these mechanisms (USEPA, 2000). Studies have shown that vegetated soils are capable of more effective degradation, removal, and mineralization of total petroleum hydrocarbons (TPHs), polycyclic aromatic hydrocarbons (PAHs), pesticides, chlorinated solvents, and surfactants than are non-vegetated soils (USEPA, 2000). Certain plant roots can absorb or immobilize metal pollutants, including cadmium, copper, nickel, zinc, lead, and chromium, while other species are capable of metabolizing or accumulating organic and nutrient contaminants. A University of Maryland study found significant metal accumulation in creeping juniper plants in pilot-scale bioretention cells. Copper increased by a factor of 6.3, lead by a factor of 77, and zinc by a factor of 8.1 in the tissue of junipers after receiving synthetic stormwater applications compared to pre-application tissue samples (Davis, Shokouhian, Sharma,

Minami and Winogradoff, 2003). An intricate and complex set of relationships and interactions between plants, microbes, soils, and contaminants make these various phytoremediation processes possible (see Appendix 5 for a more detailed discussion of phytoremediation and stormwater).

- *Plant resistance* occurs as plant materials reduce flow velocities and increase other pollutant removal pathways such as sedimentation, filtering, and plant uptake of pollutants during growth periods.
- *Volatilization* occurs when a substance is converted to a more volatile vapor form. Transforming complex hydrocarbons to carbon dioxide is an example of volatilization active in bioretention cells (Prince George's County, 2002).
- *Thermal attenuation* reduces water temperatures as storm flows move through subsurface soil layers. A field study in Maryland found that the temperature of the input water was reduced by approximately 12 degrees C after infiltrating through a bioretention cell located in a parking lot (USEPA, 2000a).

Pollutant removal efficiency in bioretention areas

Metals

Laboratory and field research indicates that bioretention areas have excellent removal capabilities for heavy metals. Duration and flow rate can influence removal at shallow depths (10 inches), but not deeper in the soil profile (36 inches). Metal adsorption in soil is typically influenced by pH; however, the buffering capacity in the bioretention soil mix effectively negates the influence of pH variations in synthetic pollutant mixtures applied to pilot-scale systems (Davis et al., 2003). The most significant metal uptake occurs in the mulch layer that can retain a large portion of the total metals loads (Davis et al., 2001).

Table 6.1.1 summarizes percentages of pollutants removed from pilot-scale laboratory studies performed at University of Maryland. Also see Appendix 4 for summaries of bioretention swale and bioretention cell research. Table 6.1.2 provides data summarizing research on other typical stormwater BMPs for comparison.

Table 6.1.1 Percent pollutant removal by depth in bioretention facilities.

Depth (inches)	Cu (µg/L)	Pb (µg/L)	Zn (µg/L)	P (mg/L)	TKN (mg/L)	NH4 (mg/L)	NO3 (mg/L)	TN (mg/L)
10	90	93	87	0	37	54	-97	-29
22	93	>97	>96	73	60	86	-194	0
36	93	>97	>96	81	68	79	23	43

Adapted from Davis et al., 1998 (removal percentages are for total metals)

Table 6.1.2 Comparative pollutant removal capability of stormwater treatment practices (in percentages).

Pollutant	Dry Extended Detention Pond	Wetlands	Water Quality Swales	Ditches
TN (mg/L)	31	30	84	-9
NO3 (mg/L)	ND	ND	ND	ND
P (mg/L)	20	49	34	-16
Cu (µg/L)	26	40	51	14
Pb (µg/L)	54	68	67	17
Zn (µg/L)	26	44	71	0

Adapted from CWP, 2000b (removal percentages are for total metals)

Nutrients

Phosphorus removal in bioretention soils increases with depth of facility. Sorption of phosphorus onto aluminum, iron, and clay minerals in the soil is the likely mechanism of removal (Davis et al., 2001). Phosphorus can **desorb** if low pH or low oxygen conditions are present; accordingly, bioretention planting soil dewatering rate and drying should be maintained and pH monitored annually. Nitrate removal is highly variable, but generally poor and at times nitrate production and export has been observed (Kim et al., 2003). Production or export of nitrate is a result of organic and ammonia nitrogen that is converted to nitrate between storms (presumably through the **ammonification** and **nitrification** process). Nitrate is then washed from the facility during subsequent storm events (Kim et al., 2003).

Where nitrate is a concern, an under-drain can be elevated from the bottom of the bioretention facility and within the gravel blanket to create a fluctuating anaerobic/aerobic zone below the drain pipe. With a suitable carbon source (e.g., wood chips mixed in the gravel) acting as an electron donor, the anaerobic zone can enhance the denitrification process (see Figure 6.1.13 in the Under-drain section) (Kim et al., 2003).

Hydrocarbons and bacteria

Hong, Seagren and Davis (2002) examined the capacity of a mulch layer to capture oil and grease via sorption and filtration. Simulated stormwater runoff carrying naphthalene was applied to a bench-scale "reactor" with a 3-cm thick leaf compost layer. During the simulated storm event approximately 90 percent of dissolved naphthalene was removed from aqueous phase via sorption. After the simulated storm event (37 and 40 hours) approximately 32 percent of the naphthalene was removed from the solid phase via biodegradation in the mulch layer where the microbial population had been inhibited. Approximately 72 percent of the naphthalene was removed from the solid phase via biodegradation in the mulch layer at 37 and 40 hours and 95 percent after 74 hours where the microbial population was not inhibited. Losses due to volatilization were negligible. See bioretention research in Appendix 4 for more detail. No research for bacteria removal in bioretention areas has currently been located.

Stormwater pollutants can disrupt normal soil function by lowering cation exchange capacity. The oldest bioretention facilities operating in the U.S. (approximately 10 years) appear to develop soil structure and maintain soil functions that actually enhance pollutant processing capability (Prince George's County, 2002). Estimates from research suggest that metal accumulation would not present an environmental concern for at least 20 years in bioretention systems (Davis et al., 2003).

Flow control processes in bioretention

- *Evaporation* can occur as precipitation is intercepted by vegetation, from surface water in the ponding area, and from exposed soil or mulch layers in bioretention areas. Evaporation from vegetation is relatively minor unless the cell has a well developed, closed, and varied canopy.
- *Infiltration* is the downward migration of runoff through the planting soil and into the surrounding soils. Infiltration is the primary mechanism for attenuating storm flows in bioretention areas. In general, long-term infiltration rates degrade over time in typical infiltration facilities due to large hydrologic loads, biofilm, and sedimentation. Anecdotal information suggests that properly designed bioretention area soil infiltration rates do not degrade as rapidly and may improve over time due to biological, chemical, and physical processes that build soil structure. Focused studies have not confirmed this. The surrounding soil will be the limiting infiltration rate in till, compacted silt or clay or other tight soils; however, there are no studies quantifying vertical and lateral subsurface flows from bioretention areas in the Puget Sound region.

Flow control performance

In the city of Seattle, Seattle Public Utilities narrowed 660 feet of conventional residential road and installed bioretention swales within the right-of-way as part of the Street Edge Alternatives (SEA) Street project. A v-notch weir installed at the ultimate outfall of the project measured surface flow volumes and timing. The contributing area with swales is approximately 2.3 acres. Soils underlying the bioretention swales are heterogeneous till-like material with lens of silt, sand, and gravel of varying permeability. Some of the swales are lined with bentonite to restrict infiltration and reduce concerns of wet basements in homes near the swales. Flows for the conventional pre-construction street were compared to the retrofit design. During the pre-construction period (March-July 2000), 7.96 inches of rainfall produced 4979 cubic feet of runoff. During the post-construction period (March-July 2001), 9.00 inches of precipitation produced 132 cubic feet of runoff. Post-construction runoff volumes were reduced by approximately 97 percent compared to pre-construction volumes. An October 2003 record storm event (4.22 inches with a 32.5 hour storm duration) produced no runoff (Horner et al., 2002).

6.1.5 Costs

The city of Seattle is implementing a new Natural Drainage System Program (NDS) for retrofitting residential streets that replaces conventional curb and gutter or roadside ditches with bioretention swales. Two designs are used depending on the gradient. The SEA Street swales are designed for the lower gradient north-south streets, and the Cascade type (which incorporate catch basins or check dams between longer gravel bottom swales) are used on the higher gradient east-west streets. Both types use compost-amended soil and small trees, shrubs, and groundcover within the swale to provide enhanced storage, infiltration, and pollutant removal. (See Figure 6.1.16 for SEA Street design example.) Table 6.1.3 compares the estimated costs of a traditional curb and gutter street retrofit to a bioretention swale design with no curb and gutter and enhanced landscaping. Costs shown include comparable water quality treatment and detention volume.

Table 6.1.3 Cost comparisons for the NDS and conventional drainage designs

Street Type	**Local Street SEA Street**	**Local Street conventional**	**Collector Street Cascade**	**Collector Street Conventional**	**Broadview Green Grid**
Transportation & aesthetics	• 1 sidewalk per block • New street paving • Traffic calming • Enhanced landscaping	• 2 sidewalks per block • New street paving • No traffic calming • Convention-al landscap-ing	• No street improvement • Enhanced landscaping	• No street improvement • Conventional landscaping	• Incorporates SEA Street and Cascade type designs • 1 sidewalk per block • New paving • Enhanced landscaping
Stormwater management	• Higher protection for aquatic biota • More close-ly mimics natural hydrology • Bio-remediate pollutants	• Flood protection focus • Water quality treatment	• Improved water quality treatment • Some flood protection	• Flood protection focus • Water quality treatment	• Higher water quality and aquatic biota protection • Some flood protection
% impervious area	35%	35%	35%	35%	35%
Cost per block (330 linear ft)	$325,000	$425,000	$285,000	$520,400	Average/block $280,000

Adapted from *Cost Analysis of Natural vs. Traditional Drainage Systems Meeting NDS Stormwater Goals,* 2004

Figure 6.1.16 SEA Street bioretention swale, Seattle. *Photo by Colleen Owen*

6.2 Amending Construction Site Soils

Native soils are highly complex systems that provide essential environmental benefits including biofiltration of pollutants, nutrients for plant growth, and the storage and slow release of storm flows. The ability of soil to effectively store and slowly release water is dependent on soil texture, structure, depth, organic matter content, and biota (Washington Organic Recycling Council [WORC], 2003). Plant roots, macro fauna, and microbes tunnel, excavate, penetrate and physically and chemically bond soil particles to form stable aggregates that enhance soil structure and porosity. Micro-and macro-pores provide a balance of environments that improve water-holding capability, increase infiltration capacity, increase oxygen levels, and provide a variety of habitats necessary to support thousands of different organisms within the soil (Allen, 1994 and CH2M HILL, 2000).

Organic matter is a critical component of a functioning soil system. Mixed into the soil, organic matter absorbs water, physically separates clay and silt particles, and reduces erosion (Balousek, 2003 and WORC, 2003). Microbial populations and vegetation depend on the replenishment of organic matter to retain and slowly release nutrients for growth (Chollak, n.d.). Typically, native Puget Sound forest soils have an organic matter content of 4 to 6 percent and the sub-soils less than 1 percent (Chollak, n.d.). Construction activity removes the upper layers of soil, compacts exposed sub-soils low in organic matter, and alters the site's hydrologic characteristics by converting the predominantly subsurface flow regime of the pre-disturbance site to primarily overland flow.

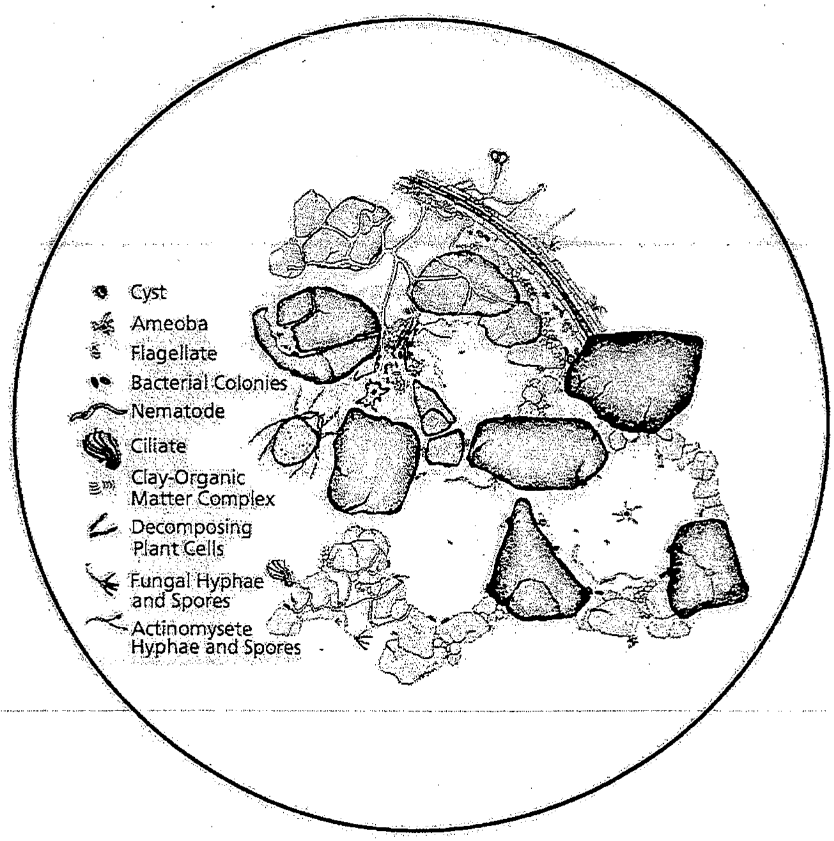

Figure 6.2.1 Close up of healthy soil structure.
Graphic courtesy of S. Rose and E.T. Elliott

Current landscape practices often do not encourage adequate preparation of turf and planting bed areas in order to regain any of the hydrologic benefits of native soils. As a result, compacted, unamended soil in landscape areas can behave similarly to impervious surfaces by generating considerable overland or shallow subsurface flows that rapidly reach receiving waters. A three-year study of a 17-hectare developed catchment near Seattle (approximately 71 percent coverage in lawn, gardens, and common areas) found that 60 percent of the total overland and rapid subsurface flow came from landscaped areas during large storms (Wigmosta, Burges and Meena, 1994). Without proper treatment and maintenance, compacted soil in lawn areas can take several years to decades to recover any beneficial infiltration and water storage characteristics of the pre-development condition (Leg, Bannerman and Panuska, 1996).

Compacted, unamended soil in landscaped areas can have similar characteristics of impervious surfaces and generate considerable overland or shallow subsurface flows that rapidly reach receiving waters.

The following section focuses on soil amendment guidelines for general landscape and vegetation protection areas. For specific application of soils in bioretention facilities see Section 6.1: Bioretention Areas.

6.2.1 Applications

The hydrologic characteristics of disturbed construction site soils for commercial, residential, and industrial projects, whether new or retrofit, can be enhanced with the addition of organic matter (CH2M HILL, 2000). In a low impact development, the landscape component of the project enhances water storage, attenuates storm flows, and is integral to the stormwater management design. When properly implemented and maintained, incorporating compost into the disturbed soils provides hydrologic, as well as other important environmental, functions including:

In a low impact development, the landscape component of the project enhances water storage, attenuates storm flows, and is integral to the stormwater management design.

- Reduced erosion.
- Increased sediment filtration.
- Pollutant adsorption and biofiltration.
- Improved plant growth, disease resistance, and overall aesthetics of the landscaping.
- Reduced (or elimination of) pesticide and fertilizer inputs for plant maintenance.
- Reduced peak summer irrigation needs (Chollak, n.d.).

Organic matter derived from compost, stockpiled on-site soil, or imported topsoil can be beneficial in all areas subject to clearing and grading. Engineered structural fill or LID drainage facilities will have specific design requirements for soil (see Section 6.1 for soil specifications in bioretention facilities). Application rates and techniques for incorporating amendments will vary with the use and plant requirements of the area. For example, application depths will be less in tree root protection zones than in turf and planting beds, and turf requiring maintenance or supporting foot traffic during the wet months will require different application rates than general landscaping areas (see Section 6.2.2: Design for details).

6.2.2 Design

Much of the information supplied here is a summary of *Guidelines and Resources for Implementing Soil Depth and Quality BMP T.5.13 in WDOE Western Washington Stormwater Manual* (Stenn, 2003). An update of this guidance is available at: http://www.soilsforsalmon.org. For details on specifications, verification, and inspection procedures, and additional resources consult the above cited manual.

To enhance the hydrologic and other environmental benefits of disturbed soils in a low impact development, the topsoil should have the following characteristics:

- A minimum organic matter content of 10 percent by dry weight for all planting beds and other landscaped areas (except turf requiring access during wet months).
- Organic matter content in turf areas that requires maintenance or supports foot traffic during the wet months should be 5 percent by dry weight.
- pH between 5.5 and 7.0 or a pH appropriate for installed plants.
- A minimum depth of 8 inches (except in tree root protection areas–see next page).
- Planting beds should be mulched with 2 to 3 inches (maximum) of organic material.
- Subsoils below topsoil applications should be scarified to a depth of at least 4 inches and some topsoil material incorporated to prevent stratification. See tilling recommendations below for specific application methods.

The minimum organic matter content may be achieved by using the pre-approved amendment methods as outlined below, or by calculating a custom amendment rate for the existing site soil conditions. The pre-approved method simplifies planning and implementation; however, the organic matter content of the disturbed on-site soils may be relatively good and not require as extensive an application of amendment material. In many cases, calculating a site-specific rate may result in significant savings in amendment material and application costs. Calculating a custom rate requires collecting soil samples from the area to be amended and samples from the compost material. The soil is then tested for bulk density and percent organic matter. The compost is tested for bulk density, percent organic matter, moisture content, carbon-to-nitrogen ratio, and heavy metals. Compost and topsoil producers can often supply the required information for the amendment material; however, on-site analysis would be necessary if vendor-supplied analysis is not available. See *Guidelines and Resources for Implementing Soil Depth and Quality BMP T.5.13 in WDOE Western Washington Stormwater Manual* (Stenn, 2003) for additional information on testing procedures.

Determining the site-specific compost application rate is calculated with the following equation:

$$CR = D\,(X)\,\frac{SBD\,(SOM\% - FOM\%)}{SBD\,(SOM\% - FOM\%) - CBD\,(COM\% - FOM\%)}$$

Where:

CR = compost application rate (inches)
D = depth of incorporation (inches)
SBD = soil bulk density *(lb/cubic yard dry weight)*
SOM% = initial soil organic matter (%)
FOM% = final target soil organic matter (%) *(target will be 5% or 10% depending on landscape area)*
CBD = compost bulk density *(lb/cubic yard dry weight)*
COM% = compost organic matter (%)

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Recommended soil characteristics can be achieved by the following methods: (1) Set aside and protect native soil and vegetation areas; (2) Amend existing disturbed topsoil or subsoil; (3) Stockpile on-site topsoil from cleared and graded areas and replace prior to planting; or (4) Import topsoil with required organic matter content standards.

1. **Set aside and protect native soil and vegetation areas.**
   The most effective and cost efficient method for providing the hydrologic benefits of healthy soil is to designate and protect native soil and vegetation areas. See Chapter 4: Vegetation Protection, Reforestation and Maintenance and Chapter 5: Clearing and Grading for conservation techniques.

The most effective and cost efficient method for providing the hydrologic benefits of healthy soil is to designate and protect native soil and vegetation areas.

2. **Amend existing disturbed topsoil or subsoil.**
   Scarify or till soil to an 8-inch depth (or to depth needed to achieve a total depth of 12 inches of uncompacted soil after the calculated amount of amendment is added). The entire surface should be disturbed by scarification and amendment applied on soil surface. Do not scarify soil within the drip-line of existing trees to be retained. Within 3 feet of the tree drip-line, amendment should be incorporated no deeper than 3 to 4 inches to reduce damage to roots.

   Landscaped Areas (10 percent organic content): Place and till 3 inches (or custom calculated amount) of composted material into 5 inches of soil (a total depth of about 9.5 inches, for a settled depth of 8 inches). Rake beds smooth, remove rocks larger than 2 inches diameter and mulch areas with 2 inches of organic mulch.

   Turf Areas (5 percent organic content): Place and till 1.75 inches (or custom calculated amount) of composted material into 6.25 inches of soil (a total amended depth of about 9.5 inches, for a settled depth of 8 inches). Water or roll to compact soil to 85 percent of maximum. Rake to level, and remove surface woody debris and rocks larger than 1-inch diameter.

3. **Stockpile on-site topsoil from cleared and graded areas and replace prior to planting.**
   Stockpile and cover soil with weed barrier or other breathable material that sheds moisture yet allows air transmission, in approved location, prior to grading. Test the stockpiled material and amend with organic matter or topsoil if required to achieve organic content to 8-inch depth. Replace stockpiled topsoil prior to planting.

   If replaced topsoil plus compost or other organic material will amount to less than 12 inches, scarify or till subgrade to a depth needed to achieve 12 inches of loosened soil after topsoil and amendment are placed. The entire surface should be disturbed by scarification and amendment applied on soil surface. Do not scarify soil within drip-line of existing trees to be retained. Within 3 feet of tree drip-line, amendment should be incorporated no deeper than 3 to 4 inches to reduce damage to roots.

   Landscaped Areas (10 percent organic content): Place and till 3 inches of composted material into 5 inches of replaced soil (a total depth of about 9.5 inches, for a settled depth of 8 inches). Rake beds to smooth, remove rocks larger than 2 inches diameter, and mulch areas with 2 inches of organic mulch or stockpiled duff.

Turf Areas (5 percent organic content): Place and till 1.75 inches of composted material into 6.25 inches of replaced soil (a total amended depth of about 9.5 inches, for a settled depth of 8 inches). Water or roll compact soil to 85 percent of maximum. Rake to level, and remove surface woody debris and rocks larger than 1-inch diameter.

4. **Import topsoil with required organic matter content standards.**

   Scarify or till subgrade in two directions to a 6-inch depth. The entire surface should be disturbed by scarification and amendment applied on soil surface. Do not scarify soil within drip-line of existing trees to be retained. Within 3 feet of tree drip-line, amendment should be incorporated no deeper than 3 to 4 inches to reduce damage to roots.

   Landscaped Areas (10 percent organic content): Use imported topsoil mix containing 10 percent organic matter (typically around 40 percent compost). The soil portion must be sand or sandy loam as defined by the USDA soil classification system. Place 3 inches of imported topsoil mix on surface and till into 2 inches of soil. Place 3 inches of topsoil mix on the surface. Rake smooth, remove surface rocks over 2 inches in diameter, and mulch planting beds with 2 inches of organic mulch.

   Turf Areas (5 percent organic content): Use imported topsoil mix containing 5 percent organic matter (typically around 25 percent compost). Soil portion must be sand or sandy loam as defined by the USDA soil classification system. Place 3 inches of topsoil mix on surface. Water or roll to compact soil to 85 percent maximum. Rake to level and remove surface rocks larger than 1-inch diameter.

   The soil portion of the topsoil must be sand or sandy loam as defined by the USDA soil classification system. The soil and compost mix should have less than 25 percent pass through a #200 sieve and 100 percent should pass through a ¾-inch screen (WORC, 2003).

Compost

Organic soil amendment, suitable for landscaping and stormwater management, should be a stable, **mature compost** derived from organic waste materials including yard debris, manures, bio-solids, wood wastes or other organic materials that meet the intent of the organic soil amendment specification. **Compost stability** indicates the level of microbial activity in the compost and is measured by the amount of CO_2 produced over a given period of time by a sample in a closed container. Unstable compost can render nutrients temporarily unavailable and create objectionable odors.

Compost quality can be determined by examining the material and qualitative tests. A simple way to judge compost quality is to smell and examine the finished product, which should have the following characteristics (WORC, 2003):

- Earthy smell that is not sour, sweet or ammonia like.
- Brown to black in color.
- Mixed particle sizes.
- Stable temperature and does not get hot when re-wetted.
- Crumbly texture.

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Qualitative tests and producer documentation should have the following specifications:

- Material must meet the definition for "composted materials" in WAC 173-350 section 220. This code is available online at http://www.ecy.wa.gov/programs/swfa/facilities/350.html.
- Organic matter content between 35 and 65 percent as determined by loss of ignition test method (ASTM D 2974).
- pH between 5.5 and 7.0.
- Carbon:nitrogen ratio between 20:1 and 35:1 (a CN ratio of 35:1 is preferred for native plantings).
- Maximum electrical conductivity of 3 ohms/cm.
- Moisture content range between 35 and 50 percent.
- No viable weed seeds.
- Manufactured inert material (plastic, concrete, ceramics, etc.) should be less than 1 percent on a dry weight or volume basis.
- Metals should not be in excess of limits in the following table:

Metal	Limit (mg/kg dry weight)
Arsenic	≤ 20 ppm
Cadmium	≤ 10 ppm
Copper	≤ 750 ppm
Lead	≤ 150 ppm
Mercury	≤ 8 ppm
Molybdenum	≤ 9 ppm
Nickel	≤ 210 ppm
Selenium I	≤ 18 ppm

(Stenn, 2003)

Determining final grade with amended soils

To achieve the appropriate grade, changes in soil depth from tilling and incorporating soil amendments need to be estimated.

The difference in volume of the dense versus the loose soil condition is determined by the "fluff factor" of the soil. The fluff factor of compacted subsoils in the Puget Sound area tends to be between 1.3 and 1.4. Tilling typically penetrates the upper 6 to 8 inches of the existing soil. Assuming a 6-inch depth is achieved, the depth adjusted by the fluff factor will correspond to a 7.8 to 8.4-inch depth of loose soil. This loose volume is then amended at a 2:1 ratio of loose soil to compost, corresponding to an imported amendment depth of approximately 4 inches for this example. In the loose state, both the soil and compost have a high percentage of pore space (volume of total soil not occupied by solids), and the final amended soil elevation must account for compost settling into void spaces of the loose soil and compaction (this example assumes that 15 percent of the soil's void spaces become occupied by compost particles). For a fluff factor of 1.3, use a compression factor of 1.15 and for soils with a fluff factor of 1.4 use a compression factor of 1.2 (i.e., 15 to 20 percent of the soils' void spaces will become occupied by compost particles). The resulting increase in elevation for soils amended to a 6-inch depth will be approximately 3 inches. See Table 6.2.1 for an example calculation.

Table 6.2.1 Example for estimating soil depth and height changes.

Procedure	Calculation	Relative Elevation Inches
Beginning Elevation		0
Rototill soil to a depth of 6 inches and assuming 1.4-inch fluff factor	Depth achieved by machinery x fluff factor of soil: (6 x 1.4) = 8.4 8.4 – 6 = 2.4	+2.4
Add compost, 2 units soil to 1 unit compost, by loose volume	Depth of soil ÷ 2: 8.4 ÷ 2 = 4.2	+4.2
Filling of pore spaces	Depth of loose soil x percentage of pore space filled by compost addition: 8.4 x (-.15) = -1.3	-1.3
Rototill compost into soil and roll site to compact soil, assuming compression factor of 1.2	(Amended soil depth ÷ compression factor) – amended soil depth:	-2.1
Resulting Elevation Change	Sum	+3.2

Turf areas

If the site is well drained and acceptable for traditional lawn installation, then a compost-amended soil lawn will drain equally well while providing superior storm flow storage, pollutant processing, and growth medium (see Section 6.2.4: Performance for details).

If the site being considered for turf establishment does not drain well, an alternative to planting a lawn should be considered. If the site is not freely draining, turf is still being attempted, and maintenance or other activity is required during the wet months, compost amendment will still provide stormwater benefits. However, the ratio of organic matter to soil should be reduced to a maximum of 30 percent by volume. This upper limit is suggested for the Puget Sound region to reduce the spongy feel of soils with high organic matter content and potential compaction during the wet months (Chollak, n.d.). A drainage route or subsurface collection system may be necessary for composted or non-composted turf applications in poorly draining soils.

Steep slopes

WSDOT has been applying compost to condition soils on slopes ranging up to 33 percent since 1992. No stability problems have been observed as a result of the increased water holding capacity of the compost (Chollak, n.d.). Steep slope areas, which have native soils with healthy native landscapes, should be protected from disturbance. On steep slopes where native soils and vegetation are disturbed or removed, soils should be amended and re-vegetated with deep rooting plants to improve slope stability. Compost can be applied to the ground surface without incorporation to improve plant growth and prevent erosion on steep slopes that cannot be accessed by equipment.

WSDOT has been applying compost to condition soils on slopes ranging up to 33 percent since 1992. No stability problems have been observed as a result of the increased water holding capacity of the compost.

6.2.3 Maintenance

- Incorporate soil amendments at the end of the site development process.
- Protect amended areas from excessive foot traffic and equipment to prevent compaction and erosion.
- Plant and mulch areas immediately after amending soil to stabilize site as soon as possible.
- Minimize or eliminate use of pesticides and fertilizers. Landscape management personnel should be trained to adjust chemical inputs accordingly and manage the landscape areas to minimize erosion, recognize soil and plant health problems, and optimize water storage and soil permeability.

6.2.4 Performance

The surface bulk density of construction site soils generally range from 1.5 to 2.0 gm/cc (CWP, 2000a). At 1.6 to 1.7 gm/cc plant roots cannot penetrate soil and oxygen content, biological activity, nutrient uptake, porosity, and water holding capacity are severely degraded (CWP, 2000a and Balousek, 2003). Tilling alone has limited effect for reducing the bulk density and enhancing compacted soil. A survey of research examining techniques to reverse soil compaction by Schueler found that tilling reduced bulk density by 0.00 to 0.15 gm/cc. In contrast, tilling with the addition of compost amendment decreased bulk density by 0.25 to 0.35 gm/cc (CWP, 2000a).

Balousek (2003) prepared combinations of deep tillage, chisel plow, and compost amended plots on an area with silt loam soil that was cleared and graded to simulate construction site conditions. The deep-tilled plots increased runoff volume compared to the control, and the combined chisel plow and deep-tilled treatment reduced runoff volume by 36 to 53 percent. With compost added to the combined plow and till treatment, runoff volume was reduced by 74 to 91 percent.

Research plots at University of Washington, prepared with various amounts and types of compost mixed with till soil and planted with turf, generated 53 to 70 percent of the runoff volume observed from the unamended control plots. The greatest attenuation was observed in treatments with a ratio of 2 parts soil to 1 part fine, well-aged compost. The study indicates that using compost to amend lawn on till soils can "significantly enhance the ability of the lawn to infiltrate, store and release water as baseflow" (Kolsti, Burges, and Jensen, 1995).

6.3 Permeable Paving

Permeable paving surfaces are designed to accommodate pedestrian, bicycle, and vehicle traffic while allowing infiltration, treatment, and storage of stormwater. The general categories of permeable paving systems include:

- *Open-graded concrete or hot-mix asphalt pavement,* which is similar to standard pavement, but with reduced or eliminated fine material (sand and finer) and special admixtures incorporated (optional). As a result, channels form between the aggregate in the pavement surface and allow water to infiltrate.
- *Aggregate or plastic pavers* that include cast-in-place or modular pre-cast blocks. The cast-in-place systems are reinforced concrete made with reusable forms. Pre-cast systems are either high-strength Portland cement concrete or plastic blocks. Both systems have wide joints or openings that can be filled with soil and grass or gravel.

Permeable paving surfaces accommodate pedestrian, bicycle, and vehicle traffic while allowing infiltration, treatment and storage of stormwater.

- *Plastic grid systems* that come in rolls and are covered with soil and grass or gravel. The grid sections interlock and are pinned in place.

6.3.1 Applications

Typical applications for permeable paving include industrial and commercial parking lots, sidewalks, pedestrian and bike trails, driveways, residential access roads, and emergency and facility maintenance roads. Highways and other high traffic load roads have not been considered appropriate for permeable paving systems. However, porous asphalt has proven structurally sound and remained permeable in a highway application on State Route 87 near Phoenix, Arizona and permeable concrete and pavers have been successfully used in industrial settings with high vehicle loads (Hossain, Scofield and Meier, 1992).

Figure 6.3.1 The residential access road at Jordan Cove Urban Monitoring Project in Connecticut is paved entirely with permeable pavers.
Photo by Tom Wagner

Benefits of permeable pavement

Initial research indicates that properly designed and maintained permeable pavements can virtually eliminate surface flows for low intensity storms common in the Pacific Northwest; store or significantly attenuate subsurface flows (dependent on underlying soil and aggregate storage design); and provide water quality treatment for nutrients, metals, and hydrocarbons (see Section 6.3.4: Performance for additional information).

Permeable paving systems have been designed with aggregate storage to function as infiltration facilities with relatively low subgrade infiltration rates (as low as 0.1 inch/hour). When water is not introduced from adjacent areas, these systems have a lower contribution to infiltration area ratio than conventional infiltration facilities (i.e., 1 to 1) and are less likely to have excessive hydraulic loading. Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. If design constraints require that surface flow be introduced from adjacent areas, particular caution should be taken to ensure that excessive sediment is not directed to the system or that additional flows will not exceed the hydraulic loading capability.

The permeable paving systems examined in this section provide acceptable surfaces for disabled persons. WAC 51-40-1103 Section 1103 (Building Accessibility) states that abrupt changes in height greater than ¼ inch in accessible routes of travel shall be beveled to 1 vertical in 2 horizontal. Changes in level greater than ½ inch shall be accomplished with an approved ramp. Permeable asphalt and concrete, while rougher than conventional paving, do not have abrupt changes in level when properly installed. The concrete pavers have small cells filled with aggregate to a level just under the top of the paver, as well as beveled edges. Gravel pave systems use a specific aggregate with a reinforcing grid that creates a firm and relatively smooth surface (see Section 6.3.2: Design).

Two qualifications for use of permeable paving and disabled access should be noted. Sidewalk designs incorporate scoring, or more recently, truncated domes, near the curb ramp to indicate an approaching traffic area for the blind. The rougher surfaces of permeable paving may obscure this transition; accordingly, standard concrete with scoring or concrete pavers with truncated domes should be used for curb ramps (Florida Concrete and Products Association [FCPA], n.d.). Also, the aggregate within the cells of permeable pavers (such as Eco-Stone) can settle or be displaced from vehicle use. As a result, paver installations for disabled parking spaces and walkways may need to include solid pavers. Individual project designs should be tailored to site characteristics and local regulatory requirements.

Many individual products with specific design requirements are available and cannot all be examined in this manual. To present a representative sample of widely applied products, this section will examine the design, installation, maintenance, and performance of permeable hot-mix asphalt, Portland cement concrete, a concrete paver system, and a flexible plastic grid system.

6.3.2 Design

Handling and installation procedures for permeable paving systems are different from conventional pavement. For the successful application of any permeable paving system three general guidelines must be followed.

For successful application of any permeable paving system follow these three general guidelines:

- *Use correct design specifications.*
- *Use qualified contractors.*
- *Strictly control erosion and sediment.*

1. **Correct design specifications**
   Proper site preparation, correct aggregate base and wearing course gradations, separation layer, and under-drain design (if included) are essential for adequate infiltration, storage, and release of storm flows, as well as structural integrity. For example, over compaction of the underlying soil and excessive fines present in the base or top course will significantly degrade or effectively eliminate the infiltration capability of the system.

2. **Qualified contractors**
   Contractors must be trained and have experience with the product, and suppliers must adhere to material specifications. Installation contractors should provide data showing successful application of product specifications for past projects. If the installation contractor does not have adequate experience the contractor should retain a qualified consultant to monitor production, handling, and placement operations (U.S. Army Corps of Engineers, 2003). Substituting inappropriate materials or installation techniques will likely result in structural or hydrologic performance problems. For example, using vibrating plate compactors (typical concrete installation procedure) with excessive pressures and frequencies will seal the void spaces in permeable cast-in-place concrete.

3. **Sediment and erosion control**
   Erosion and introduction of sediment from surrounding land uses should be strictly controlled during and after construction to reduce clogging of the void spaces in the base material and permeable surface. Filter fabric between the underlying soil and base material is required to prevent soil fines from migrating up and into the aggregate base. Muddy construction equipment should not be allowed on the base material or pavement, sediment laden runoff

should be directed to pre-treatment areas (e.g., settling ponds and swales), and exposed soil should be mulched, planted, and otherwise stabilized as soon as possible.

The preceding guidelines are not optional for the installation of permeable paving systems. Past design failures are most often attributed to not adhering to the above general guidelines, and failure is likely without qualified contractors and strict adherence to correct installation specifications.

Properly designed permeable paving installations have performed well in the Midwestern and Northeastern U.S. where freeze-thaw cycles are severe (Adams, 2003 and Wei, 1986). Risk of freeze damage can be minimized by extending the base of the permeable paving system to a minimum of half the freeze depth. For example, a total minimum depth for the wearing course and aggregate base material would be 6 inches in the Seattle area, where the freeze-thaw depth is 12 inches (Diniz, 1980).

Determining infiltration rates

Depending on the design, permeable paving installations can be modeled as landscaped area over the underlying soil type or as an infiltration basin. If the installation is modeled as an infiltration basin, determining the infiltration rate of the underlying soil is necessary to equate flow reduction benefits when using the WWHM or MGS Flood. For details on flow modeling guidance see Chapter 7. See Figure 6.3.2 for a graphic representation of the process to determine infiltration rates. The following tests are recommended for soils below the aggregate base material:

- Small permeable paving installations (patios, walkways, and driveways on individual lots): The flow control credits on private property do not include subsurface storage; accordingly, no infiltration field tests are necessary. Soil texture, grain size analysis, or soil pit excavation and infiltration tests may still be prudent if highly variable soil conditions or seasonal high water tables are suspected.
- Large permeable paving installations (sidewalks, alleys, parking lots, roads) that include storage volume using base material below the grade of the surrounding land and the installations are modeled as an infiltration basin:
    - o Method 1: Use USDA Soil Textural Classification (Rawls survey) every 200 feet of road or every 5,000 square feet.
    - o Method 2: Use ASTM D422 Gradation Testing at Full Scale Infiltration Facilities every 200 feet of road or every 5,000 square feet. See the 2005 SMMWW Volume III for details on methods 1 and 2. This method uses the *2004 WSDOT Highway Runoff Manual* protocol.
    - o Method 3: Use small-scale infiltrometer tests every 200 feet of road or every 5,000 square feet. Small-scale infiltrometer tests such as the USEPA Falling Head or double ring infiltrometer tests (ASTM 3385-88) may not adequately measure variability of conditions in test areas. If used, measurements should be taken at several locations within the area of interest.
    - o Method 4: Pilot Infiltration Test (PIT) or small-scale test infiltration pits (septic test pits) at a rate of 1 pit/500 feet of road or 10,000 ft^2. This infiltration test better represents soil variability and is recommended for highly variable soil conditions or where seasonal high water tables are suspected. See the 2005 SMMWW Appendix III-D (formerly V-B) for PIT method description.

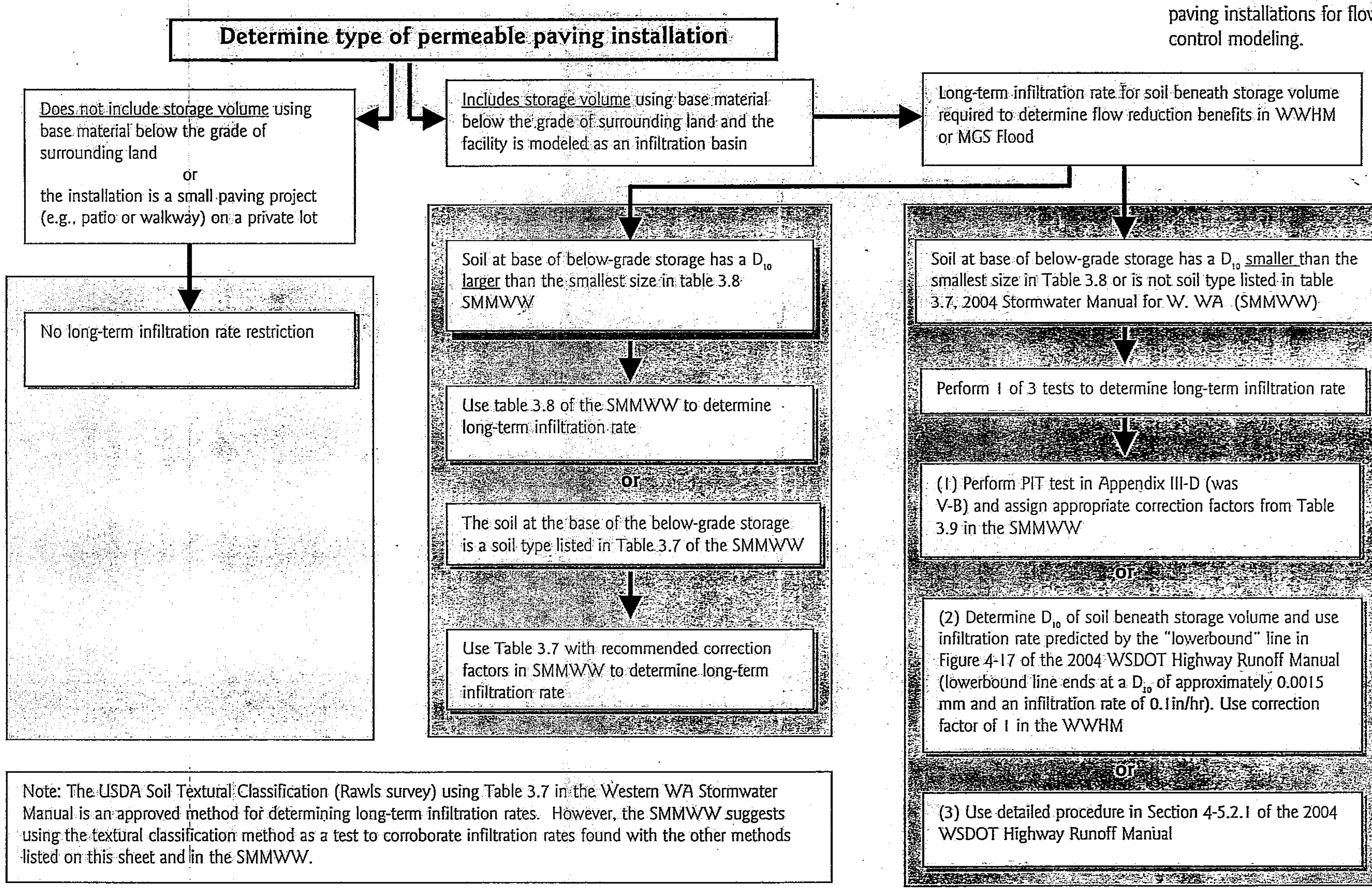

Figure 6.3.2 Determining long-term infiltration rates in soils under permeable paving installations for flow control modeling.

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Utility excavations under or beside the road section can provide pits for soil classification, textural analysis, stratigraphy analysis, and/or infiltration tests and minimize time and expense for permeable paving infiltration tests.

Components of permeable paving systems

The following provides a general description and function for the components of permeable paving systems. Design details for specific permeable paving system components are included in the section describing specific types of permeable paving.

Wearing course or surface layer

The wearing course provides compressive and flexural strength for the designed traffic loads while maintaining adequate porosity for storm flow infiltration. Wearing courses include cast-in-place concrete, asphalt, concrete and plastic pavers, and plastic grid systems. In general, permeable top courses have very high initial infiltration rates with various asphalt and concrete research reporting 28 to 1750 inches per hour when new (see Appendix 7: Porous Paving Research for details). Various rates of clogging have been observed in wearing courses and should be anticipated and planned for in the system design (see Section 6.3.5: Performance for research on infiltration rates over time). Permeable paving systems allow infiltration of storm flows; however, the wearing course should not be allowed to become saturated from excessive water volume stored in the aggregate base layer.

Aggregate base

The aggregate base provides: (1) a stable base for the pavement; (2) a highly permeable layer to disperse water downward and laterally to the underlying soil; and (3) a temporary reservoir that stores water prior to infiltration in the underlying soil or collection in under-drains for conveyance (Washington State Department of Transportation [WSDOT], 2003). Base material is often composed of larger aggregate (1.5 to 2.5 inches) with smaller stone (leveling or choker course) between the larger stone and the wearing course. Typical void space in base layers ranges from 20 to 40 percent (WSDOT, 2003 and Cahill, Adams and Marm, 2003). Depending on the target flow control standard and physical setting, retention or detention requirements can be partially or entirely met in the aggregate base. Aggregate base depths of 18 to 36 inches are common depending on storage needs and provide the additional benefit of increasing the strength of the wearing course by isolating underlying soil movement and imperfections that may be transmitted to the wearing course (Cahill et al., 2003).

Separation and water quality treatment layer

The separation layer is a non-woven geotextile fabric that provides a barrier to prevent fine soil particles from migrating up and into the base aggregate. If required, the water quality treatment layer filters pollutants from surface water and protects groundwater quality (generally, a treatment layer will be necessary in critical aquifer recharge areas). The treatment media can consist of a sand layer or an engineered amended soil. Engineered amended soil layers should be a minimum of 18 inches and incorporate compost, sphagnum peat moss or other organic material to provide a **cation exchange capacity** of ≥ 5 milliequivalents/100 grams dry soil (Ecology, 2001). Soil gradation and final mix should provide a minimum infiltration rate of 0.5 inch/hour at final compaction.

Flow modeling guidance

See Chapter 7 for guidance and flow reduction credits for permeable paving systems when using the WWHM.

A treatment layer is not required where the subgrade soil has a long-term infiltration rate of < 2.4 inches/hour and a cation exchange capacity of ≥ 5 milliequivalents/100 grams dry soil.

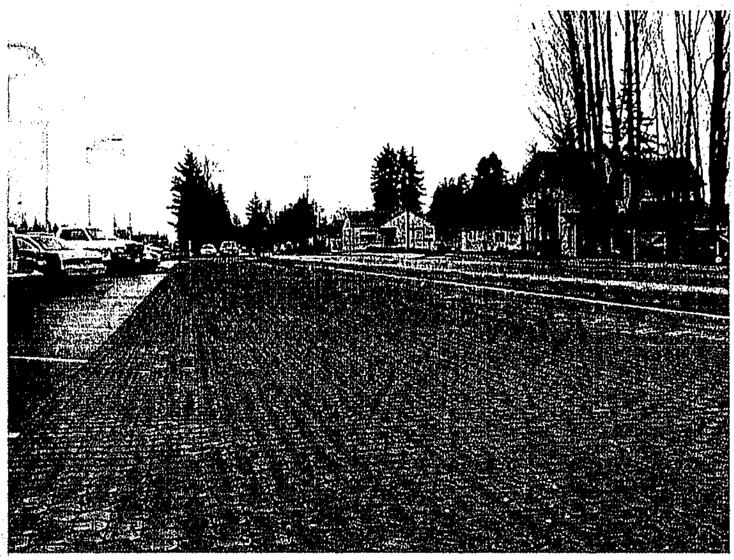


Figure 6.3.3 Permeable pavers were installed at this Marysville parking lot for infiltration. Organic material was mixed with sand as part of the sub-base to enhance treatment.
Photo by Colleen Owen

Types of permeable paving

The following section provides general design specifications for permeable hot-mix asphalt, Portland cement concrete, a flexible plastic grid system, a cement paver, and a rigid plastic block product. Each product has specific design requirements. Most notably the permeable Portland cement concrete and hot-mix asphalt differ from the paver systems in subgrade preparation. Concrete and asphalt systems are designed and constructed to minimize subgrade compaction and maintain the infiltration capacity of the underlying soils. Paver systems require subgrade compaction to maintain structural support. Some soils with high sand and gravel content can retain useful infiltration rates when compacted; however, many soils in the Puget Sound region become essentially impermeable when compacted to 95 percent modified proctor or proctor rates.

The specifications below are provided to give designers general guidance. Each site has unique characteristics and development requirements; accordingly, qualified engineers and other design disciplines should be consulted for developing specific permeable paving systems.

1. Permeable hot-mix asphalt

Permeable asphalt is similar to standard hot-mix asphalt; however, the aggregate fines (particles smaller than No. 30 sieve) are reduced, leaving a matrix of pores that conduct water to the underlying aggregate base and soil (Cahill et al., 2003). Porous asphalt can be used for light to medium duty applications including residential access roads, driveways, utility access, parking lots, and walkways; however, porous asphalt has been used for heavy applications such as airport runways (with the appropriate polymer additive to increase bonding strength) and highways (Hossain, Scofield and Meier, 1992). While freeze-thaw cycles are not a large concern in

Properly installed and maintained permeable asphalt should have a service life that is comparable or longer than conventional asphalt.

the Puget Sound lowland, permeable asphalt can and has been successfully installed in wet, freezing conditions in the Midwestern U.S. and Massachusetts with proper section depths (Cahill et al., 2003 and Wei, 1986). Properly installed and maintained permeable asphalt should have a service life that is comparable or longer than conventional asphalt (personal communication, Tom Cahill, 2003).

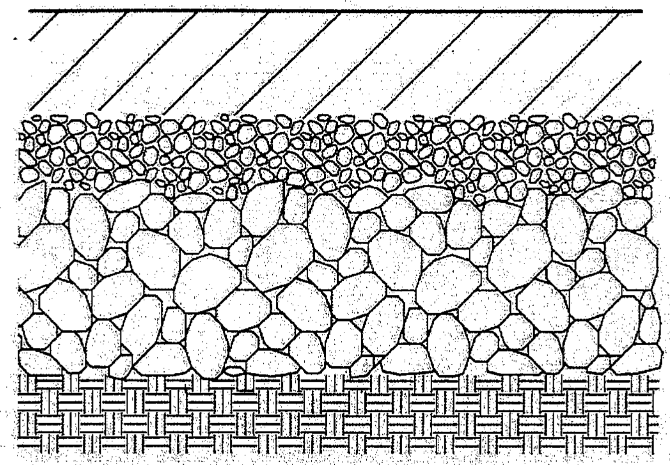


Figure 6.3.4 Permeable asphalt section.

Graphic by AHBL Engineering

Design

Several permeable bituminous asphalt mixes and design specifications have been developed for friction courses (permeable asphalt layer over conventional asphalt) and as wearing courses that are composed entirely of a porous asphalt mix. The friction courses are designed primarily to reduce noise and glare off standing water at night and hydroplaning; however, this design approach provides minimal attenuation of stormwater during the wet season in the Puget Sound region. The following provides specifications and installation procedures for permeable asphalt applications where the wearing top course is entirely porous, the base course accepts water infiltrated through the top course, and the primary design objective is to significantly or entirely attenuate storm flows.

Application: parking lots, driveways, and residential and utility access roads.

Soil infiltration rate

- As long as runoff is not directed to the permeable asphalt from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.1 inch/hour. Soils with lower infiltration rates should have under-drains to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section.
- Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. Surface flows from adjacent areas can introduce excess sediment, increase clogging, and result in excessive hydrologic loading. However, it may be acceptable to direct flows after treatment to the subgrade if storage volume and infiltration rates allow.

Subgrade

- Soil conditions should be analyzed by a qualified engineer for load bearing given anticipated soil moisture conditions.

- After grading, the existing subgrade should not be compacted or subjected to excessive construction equipment traffic.
- If using the base course for retention in parking areas, excavate the storage bed level to allow even distribution of water and maximize infiltration across entire parking area.
- Immediately before base aggregate and asphalt placement, remove any accumulation of fine material from erosion with light equipment and scarify soil to a minimum depth of 6 inches.

Aggregate base/storage bed

- Minimum base depth for structural support should be 6 inches (Washington State Department of Transportation, 2003).
- Maximum depth is determined by the extent to which the designer intends to achieve a flow control standard with the use of a below-grade storage bed. Aggregate base depths of 18 to 36 inches are common depending on storage needs.
- Coarse aggregate layer should be a 2.5- to 0.5-inch uniformly graded crushed (angular) thoroughly washed stone (AASHTO No. 3).
- Choker course should be 1 to 2 inches in depth and consist of 1.5-inch to U.S. sieve size number 8 uniformly graded crushed washed stone for final grading of base reservoir. The upper course is needed to reduce rutting from construction vehicles delivering and installing asphalt and to more evenly distribute loads to the base material (Diniz, 1980).

Installation of Aggregate base/storage bed

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- Install approved non-woven filter fabric on subsoil according to manufacturer's specifications. Where installation is adjacent to conventional paving surfaces, filter fabric should be wrapped up sides to top of base aggregate to prevent migration of fines from densely graded material to the open graded base, maintain proper compaction, and avoid differential settling.
- Overlap adjacent strips of fabric at least 24 inches. Secure fabric 4 feet outside of storage bed to reduce sediment input to bottom of area storage reservoir.
- Install coarse (1.5 to 2.5 inch) aggregate in maximum of 8-inch lifts and lightly compact each lift.
- Install a 1 to 2-inch choker course evenly over surface of course aggregate base.
- Following placement of base aggregate and again after placement of the asphalt, the filter fabric should be folded over placements to protect installation from sediment inputs. Excess filter fabric should not be trimmed until site is fully stabilized (U.S. Army Corps of Engineers, 2003).

Top course

- Parking lots: 2 to 4 inches typical.
- Residential access roads: 2 to 4 inches typical.
- Permeable asphalt has similar strength and flow properties as conventional asphalt; accordingly, the wearing course thickness is similar for either surface given equivalent load requirements (Diniz, 1980).

Aggregate grading:	U.S. Standard Sieve	Percent Passing
	1/2	100
	3/8	92-98
	4	32-38
	8	12-18
	16	7-13
	30	0-5
	200	0-3

- A small percentage of fine aggregate is necessary to stabilize the larger porous aggregate fraction. The finer fraction also increases the viscosity of the asphalt cement and controls asphalt drainage characteristics.
- Total void space should be approximately 16 percent (conventional asphalt is 2 to 3 percent) (Diniz, 1980).

Bituminous asphalt cement

- Content: 5.5 to 6.0 percent by weight dry aggregate. The minimum content assures adequate asphalt cement film thickness around the aggregate to reduce photo-oxidation degradation and increase cohesion between aggregate. The upper limit is to prevent the mixture from draining during transport.
- Grade: 85 to 100 penetration recommended for northern states (Diniz, 1980).
- An elastomeric polymer can be added to the bituminous asphalt to reduce drain-down.
- Hydrated lime can be added at a rate of 1.0 percent by weight of the total dry aggregate to mixes with granite stone to prevent separation of the asphalt from the aggregate and improve tensile strength.

General installation

- Install permeable asphalt system toward the end of construction activities to minimize sediment problems. The subgrade can be excavated to within 6 inches of final grade and grading completed in later stages of the project (Cahill et al., 2003).
- Erosion and introduction of sediment from surrounding land uses should be strictly controlled during and after construction. Erosion and sediment controls should remain in place until area is completely stabilized with soil amendments and landscaping.
- Adapting aggregate specifications can influence bituminous asphalt cement properties and permeability of the asphalt wearing course. Before final installation, test panels are recommended to determine asphalt cement grade and content compatibility with the aggregate (Diniz, 1980).
- Insulated covers over loads during hauling can reduce heat loss during transport and increase working time (Diniz, 1980). Temperatures at delivery that are too low can result in shorter working times, increased labor for hand work, and increased cleanup from asphalt adhering to machinery (personal communication Leonard Spodoni, April 2004).

Backup systems for protecting permeable asphalt systems

- For backup infiltration capacity (in case the asphalt top course becomes clogged) an unpaved stone edge can be installed that is hydrologically connected to the storage bed (see Figure 6.3.5).

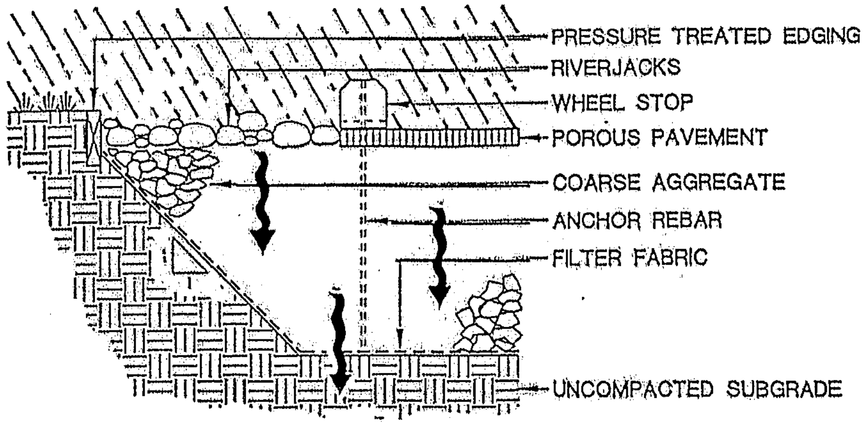


Figure 6.3.5 Unpaved section (river jacks) provides backup infiltration.
Graphic courtesy of Cahill Associates

- As with any paving system, rising water in the underlying aggregate base should not be allowed to saturate the pavement (Cahill et al., 2003). To ensure that the asphalt top course is not saturated from excessively high water levels in the aggregate base (as a result of subgrade soil clogging), a positive overflow can be installed.

For a sample specification for permeable asphalt paving see Appendix 8.

Cost

Materials and mixing costs for permeable asphalt are similar to conventional asphalt. In general, local contractors are currently not familiar with permeable asphalt installation, and additional costs for handling and installation should be anticipated. Estimates for porous pavement material and installation are approximately $.60 to .70/square foot and will likely be comparable to standard pavement as contractors become more familiar with the product. Due to the lack of experience regionally, this is a rough estimate. The cost for base aggregate will vary significantly depending on base depth for stormwater storage and is not included in the cost estimate.

2. Portland cement permeable concrete

Florida and Georgia use permeable concrete extensively for stormwater management. The material and installation specifications in Washington are derived primarily from the field experience and testing through the Florida Concrete and Products Association. In the Puget Sound region, the cities of Seattle and Olympia and Stoneway Concrete have tested materials and installed several projects including parking lots, sidewalks, and driveways.

Permeable Portland cement concrete is similar to conventional concrete without the fine aggregate (sand) component. The mixture is a washed coarse aggregate (3/8 or 5/8 inch), hydraulic cement, admixtures (optional) and water, yielding a surface with a matrix of pores that conducts water to the underlying aggregate base and soil. Permeable concrete can be used for light to medium duty applications including residential access roads, driveways, utility access, parking lots, and walkways. Permeable concrete can also be used in heavy load applications. For example, test sections in a city of Renton aggregate recycling yard have performed well structurally after being subjected to regular 50,000- to 100,000-pound vehicle loads for the past three years (personal communication, Greg McKinnon, March 2004). Properly installed and maintained concrete should have a service life comparable to conventional concrete.

Designing the aggregate base to accommodate retention or detention storage will depend on several factors, some of which include project specific stormwater flow control objectives, costs, and regulatory restrictions. However, deeper subgrade to base courses (e.g., 12 to 36 inches) can provide important benefits including significant reduction of above ground stormwater retention or detention needs and uniform subgrade support (FCPA, n.d.). Base courses that are placed above the surrounding grade cannot be used, or given credit for, reducing retention or detention pond sizes. (See Chapter 7 for flow modeling guidance and flow reduction credits.)

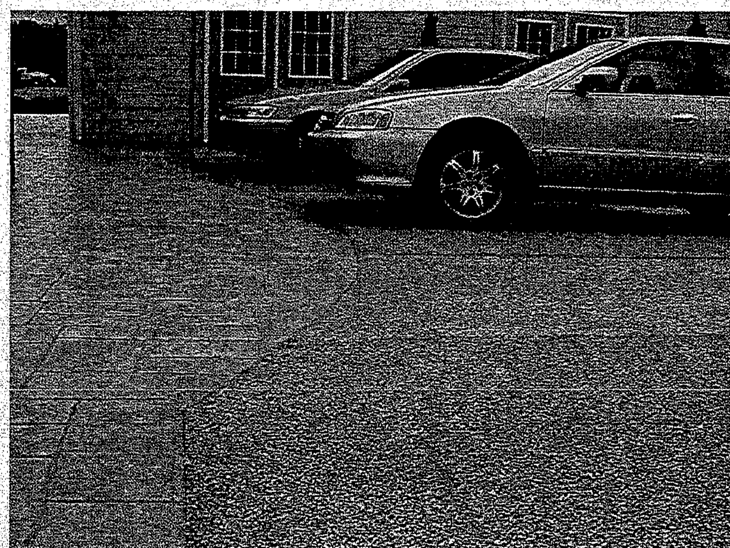


Figure 6.3.6 Permeable concrete adjacent to stamped concrete in Des Moines.
Photo by Curtis Hinman

Design and installation

Three general classes of permeable concrete are prevalent: (1) the standard mix using washed course aggregate (3/8 or 5/8 inch), hydraulic cement, admixtures (optional) and water; (2) a Stoneycrete mixture which is similar to the standard mix, but incorporates a strengthening additive; and (3) Percocrete which uses a higher percentage of sand, incorporates an additive to enhance strength and the pore structure, and produces a smoother surface texture. The following design section examines the standard concrete mix. Additional information for Stoneycrete is available at Stoney Creek Materials L.L.C. Austin, Texas and for Percocrete at Michiels International Inc., Kenmore, Washington.

Application: parking lots, driveways, sidewalks, utility access, and residential roads.

Soil infiltration rate

- If runoff is not directed to the permeable concrete from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.1 inch/hour. Soils with lower infiltration rates should have under-drains to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section.
- Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. Surface flows from adjacent areas can introduce excess sediment, increase clogging, and result in excessive hydrologic loading.

However, it may be acceptable to direct flows after treatment to the subgrade if storage volume and infiltration rates allow.

Subgrade

- Soil conditions should be analyzed for load bearing given anticipated soil moisture conditions by a qualified engineer.
- After grading, the existing subgrade should not be compacted or subject to excessive construction equipment traffic (U.S. Army Corps of Engineers, 2003).
- Immediately before base aggregate and concrete placement, remove any accumulation of fine material from erosion with light equipment and scarify soils to a minimum depth of 6 inches if compacted (U.S. Army Corps of Engineers, 2003).

Aggregate base/storage bed

- Minimum base depth for structural support should be 6 inches (FCPA, n.d.).
- Maximum depth is determined by the extent to which the designer intends to achieve a flow control standard with the use of a below-grade storage bed. Aggregate base depths of 18 to 36 inches are common when designing for retention or detention.
- The coarse aggregate layer varies depending on structural and stormwater management needs. Typical placements include round or crushed washed drain rock (1 to 1.5 inches) or 1.5 to 2.5-inch crushed washed base rock aggregate (e.g., AASTHO No. 3).
- The concrete can be placed directly over the coarse aggregate or a choker course (e.g., 1.5 inch to US sieve size number 8, AASHTO No 57 crushed washed stone) can be placed over the larger stone for final grading.

Installation of aggregate base/storage bed

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed..
- If using the aggregate base for retention in parking areas, excavate storage bed level to allow even distribution of water and maximize infiltration across entire parking area.
- Install approved non-woven filter fabric on subsoil according to manufacturer's specifications. Where concrete installations are adjacent to conventional paving surfaces the filter fabric should be wrapped up the sides and to the top of base aggregate to prevent migration of fines from the densely graded base to the open graded base material, maintain proper compaction, and avoid differential settling.
- Overlap adjacent strips of fabric at least 24 inches. Secure fabric 4 feet outside of storage bed to reduce sediment input to bottom of storage reservoir.
- Install coarse aggregate in maximum of 8-inch lifts and lightly compact each lift (U.S. Army Corps of Engineers, 2003).
- If utilized, install a 1-inch choker course evenly over surface of coarse aggregate base (typically No. 57 AASHTO) and lightly compact.
- Following placement of base aggregate and again after placement of concrete, the filter fabric should be folded over placements to protect installation from sediment inputs. Excess filter fabric should not be trimmed until site is fully stabilized (U.S. Army Corps of Engineers, 2003).

Top course

- Parking lots: 4 inches typical.
- Roads: 6 to 12 inches typical.
- Unit weight: 120 to 130 pounds per cubic foot (permeable concrete is approximately 70 to 80 percent of the unit weight of conventional concrete) (FCPA, n.d.).
- Void space: 15 to 21 percent according to ASTM C 138.
- Water cement ratio: 0.27 to 0.35.
- Aggregate to cement ratio: 4:1 to 4.5:1.
- Aggregate: several aggregate specifications are used including:
  - o 3/8-inch to No. 16 washed crushed or round per ASTM C 33.
  - o 3/8-inch to No. 50 washed crushed or round per ASTM D 448.
  - o 5/8-inch washed crushed or round.
  - o In general the 3/8-inch crushed or round produces a slightly smoother surface and is preferred for sidewalks, and the 5/8-inch crushed or round produces a slightly stronger surface.
- Portland cement: Type I or II conforming to ASTM C 150 or Type IP or IS conforming to ASTM C 595.
- Admixtures: Can be used to increase working time and include: Water Reducing/Retarding Admixture in conformance with ASTM C 494 Type D and Hydration stabilizer in conformance with ASTM C 494 Type B.
- Water: Use potable water.
- Fiber mesh can be incorporated into the cement mix for added strength.

Installation of top course

- See testing section below for confirming correct mixture and proper installation.
- If mixture contains excess water the cement paste can flow from the aggregate, resulting in a weak surface layer and reduced void space in the lower portion of surface. With the correct water content, the delivered mix should have a wet metallic sheen, and when hand squeezed the mix should not crumble or become a highly plastic mass (FCPA, n.d.).
- Cement mix should be used within 1 hour after water is introduced to mix, and within 90 minutes if an admixture is used and concrete mix temperature does not exceed 90 degrees Fahrenheit (U.S. Army Corps of Engineers, 2003).
- Base aggregate should be wetted to improve working time of cement.
- Concrete should be deposited as close to its final position as possible and directly from the truck or using a conveyor belt placement.
- A manual or mechanical screed can be used to level concrete at 1/2 inch above form.
- Cover surface with 6-mil plastic and use a static drum roller for final compaction (roller should provide approximately 10 pounds per square inch vertical force).
- Edges that are higher than adjacent materials should be finished or rounded off to prevent chipping (standard edging tool is applicable for pervious concrete).
- Cement should be covered with plastic within 20 minutes and remain covered for curing time.
- Curing: 7 days minimum for Portland cement Type I and II. No truck traffic should be allowed for 10 days (U.S. Army Corps of Engineers, 2003).

- Placement widths should not exceed 15 feet unless contractor can demonstrate competence to install greater widths.
- High frequency vibrators can seal the surface of the concrete and should not be used.
- Jointing: Shrinkage associated with drying is significantly less for permeable than conventional concrete. Florida installations with no control joints have shown no visible shrink cracking. A conservative design can include control joints at 60 foot spacing cut to 1/4 the thickness of the pavement (FCPA, n.d. and U.S. Army Corps of Engineers, 2003). Expansion joints can also facilitate a cleaner break point if sections become damaged or are removed for utility work.

Testing

Differences in local materials, handling, and placement can affect permeable concrete performance. The following tests should be conducted even if the contractor or consultant has experience with the material to ensure proper performance.

- The contractor should place and cure two test panels, each covering a minimum of 225 square feet at the required project thickness, to demonstrate that specified unit weights and permeability can be achieved on-site (Georgia Concrete and Products Association [GCPA], 1997).
- Test panels should have two cores taken from each panel in accordance with ASTM C 42 at least 7 days after placement (GCPA, 1997).
- Untrimmed cores should be measured for thickness according to ASTM C 42.
- After determining thickness, cores should be trimmed and measured for unit weight per ASTM C 140.
- Void structure should be tested per ASTM C 138.
- If the measured thickness is greater than 1/4 inch less than the specified thickness, or the unit weight is not within ± 5 pounds per cubic foot, or the void structure is below specifications, the panel should be removed and new panels with adjusted specifications installed (U.S. Army Corps of Engineers, 2003). If test panel meets requirements, panel can be left in place as part of the completed installation.
- Collect and sample delivered material once per day to measure unit weight per ASTM C 172 and C 29 (FCPA, n.d.).

Backup systems for protecting permeable concrete systems

- For backup infiltration capacity (in case the concrete top course becomes clogged) an unpaved stone edge can be installed that is connected to the base aggregate storage reservoir (see Figure 6.3.5).
- As with any paving system, rising water in the underlying aggregate base should not be allowed to saturate the pavement (Cahill et al., 2003). To ensure that the top course is not saturated from excessively high water levels (as a result of subgrade soil-clogging), a positive overflow can be installed in the base.

Cost

Permeable concrete material and installation is approximately $3.00 to $5.00 per square foot depending on surface thickness and site conditions. Cost for base aggregate will vary significantly depending on base depth for stormwater storage and is not included in the cost estimate.

3. Eco-Stone permeable interlocking concrete pavers

Eco-Stone is a high-density concrete paver that allows infiltration through a built-in pattern of openings filled with aggregate. When compacted, the pavers interlock and transfer vertical loads to surrounding pavers by shear forces through fine aggregate in the joints (Pentec Environmental, 2000). Eco-Stone interlocking pavers are placed on open graded sub-base aggregate topped with a finer aggregate layer that provides a level and uniform bedding material. Properly installed and maintained, high-density pavers have high load bearing strength and are capable of carrying heavy vehicle weight at low speeds. Properly installed and maintained pavers should have a service life of 20 to 25 years (Smith, 2000).

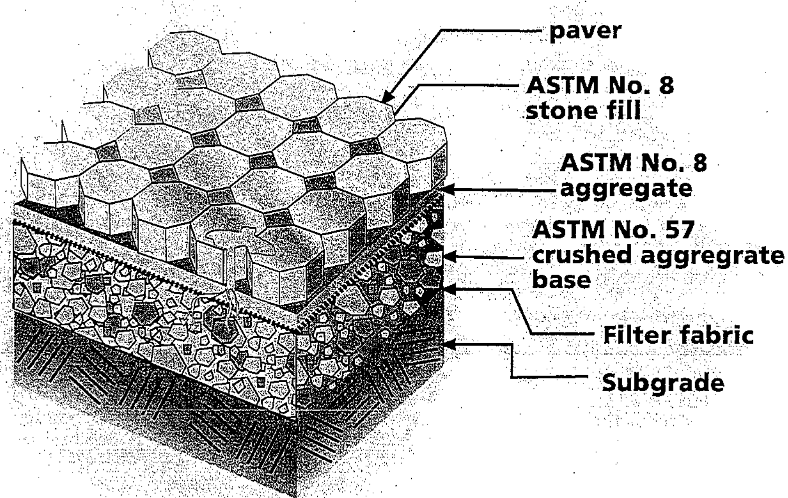


Figure 6.3.7 Permeable interlocking concrete paver section.
Graphic by Gary Anderson

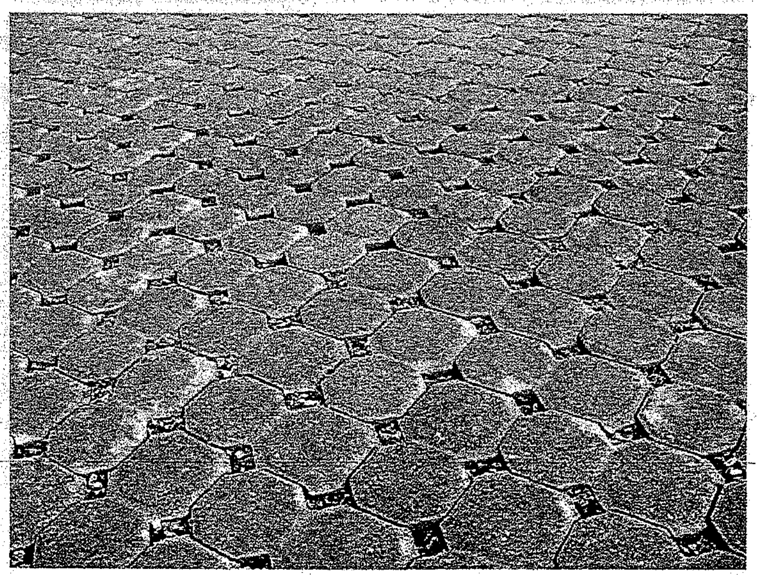


Figure 6.3.8 Close-up view of permeable pavers.
Photo by Curtis Hinman

Design

Application: Industrial and commercial parking lots, utility access, residential access roads, driveways, and walkways. Experienced contractors with a current certificate in the ICPI Contractor Certification Program should perform installations.

Soil infiltration rate

- If runoff is not directed to the permeable pavers from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.5 inch/hour. Soils with lower infiltration rates should have under-drains at the bottom of the base course to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section. Drain-down time for the base should not exceed 24 hours.
- Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. Surface flows from adjacent areas can introduce excess sediment, increase clogging, and result in excessive hydrologic loading. However, it may be acceptable to direct flows after treatment to the subgrade if storage volume and infiltration rates allow.

Subgrade

- Soils should be analyzed by a qualified engineer for infiltration rates and load bearing, given anticipated soil moisture conditions. **California Bearing Ratio** values should be at least 5 percent.
- For vehicle traffic areas, grade and compact to 95 percent modified proctor density (per ASTM D 1557) and compact to 95 percent standard proctor density for pedestrian areas (per ASTM D698) (Smith, 2000). Soils with high sand and gravel content can retain useful infiltration rates when compacted; however, many soils in the Puget Sound region become essentially impermeable at this compaction rate. For detention designs on compacted soils that will provide very low permeability, adequate base aggregate depths and under-drain systems should be incorporated to reduce risk of continued saturation that can weaken subgrades subject to vehicle traffic (Smith, 2000).

Aggregate base/storage bed

- Minimum base thickness depends on vehicle loads, soil type, stormwater storage requirements, and freeze thaw conditions. Typical depths range from 6 to 22 inches; however, increased depths can be applied for increased storage capacity (Smith, 2000). Interlocking Concrete Paver Institute guidelines for base thickness should be followed.
- Minimum base depth for pedestrian and bike applications should be 6 inches (Smith, 2000).
- ASTM No. 57 crushed aggregate or similar gradation is recommended for the sub-base (Smith, 2000).
- ASTM No. 8 is recommended for the leveling or choker course.

Installation of aggregate base/storage bed

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- If using the base course for retention in parking areas, excavate storage bed level to allow even distribution of water and maximize infiltration across entire parking area.

- Install approved non-woven filter fabric to bottom and sides of excavation according to manufacturer's specifications. Where paver installation is adjacent to conventional paving surfaces, filter fabric should be wrapped up sides to top of base aggregate to prevent migration of fines from densely graded base to the open graded base material, maintain proper compaction, and avoid differential settling. A concrete curb the depth of the base can also be used to separate the open graded and dense graded bases.
- Overlap adjacent strips of fabric at least 24 inches. Secure fabric 4 feet outside of storage bed to reduce sediment input to bottom of area storage reservoir (Smith, 2000).
- Install No. 57 aggregate in 4 to 6-inch lifts.
- Compact the moist No. 57 aggregate with at least 4 passes of a 10-ton (minimum) steel drum roller. Initial passes can be with vibration and the final two passes should be static (Smith, 2000). Testing for appropriate density per ASTM D 698 or D 1557 will likely not provide accurate results. The Interlocking Concrete Pavement Institute specification recommends that adequate density and stability are developed when no visible movement is observed in the open-graded base after compaction (personal communication, Dave Smith ICPI).
- Install three inches of No. 8 aggregate for the leveling or choker course and compact with at least 4 passes of a 10-ton roller. Surface variation should be within ± 1/2 inch over 10 feet. The No. 8 aggregate should be moist to facilitate compaction into the sub-base (Smith, 2000).
- Asphalt stabilizer can be used with the No. 57 stone if additional bearing support is needed, but should not be applied to the No. 8 aggregate. To maintain adequate void space, use a minimum of asphalt for stabilization (approximately 2 to 2.5 percent by weight of aggregate). An asphalt grade of AC20 or higher is recommended. The addition of stabilizer will reduce storage capacity of base aggregate and should be considered in the design (Smith, 2000).
- Following placement of base aggregate and again after placement of pavers, the filter fabric should be folded over placements to protect installation from sediment inputs. Excess filter fabric should not be trimmed until site is fully stabilized.
- Designs for full infiltration of stormwater to the subgrade should have a positive overflow to prevent water from entering the surface layer during extreme events. Designs with partial or no **exfiltration** require under-drains. All installations should have an observation well (typically 6-inch perforated pipe) installed at the furthest downslope area (Smith, 2000).

Top course installation

- Pavers should be installed immediately after base preparation to minimize introduction of sediment and to reduce the displacement of base material from ongoing activity (Smith, 2000).
- Loosen and evenly smooth 3/4 to 1 inch of the compacted No. 8 stone.
- Place pavers by hand or with mechanical installers and compact with a 5000 lbf, 75 to 90 Hz plate compactor. Fill openings with No. 8 stone and compact again. Sweep to remove excess stone from surface. The small amount of finer aggregate in the No. 8 stone will likely be adequate to fill narrow joints between pavers in pedestrian and light vehicle applications. If the installation is subject

to heavy vehicle loads, additional material may be required for joints. Sweep in additional material (ASTM No. 89 stone is recommended) and use vibratory compaction to place joint material (Smith, 2000).

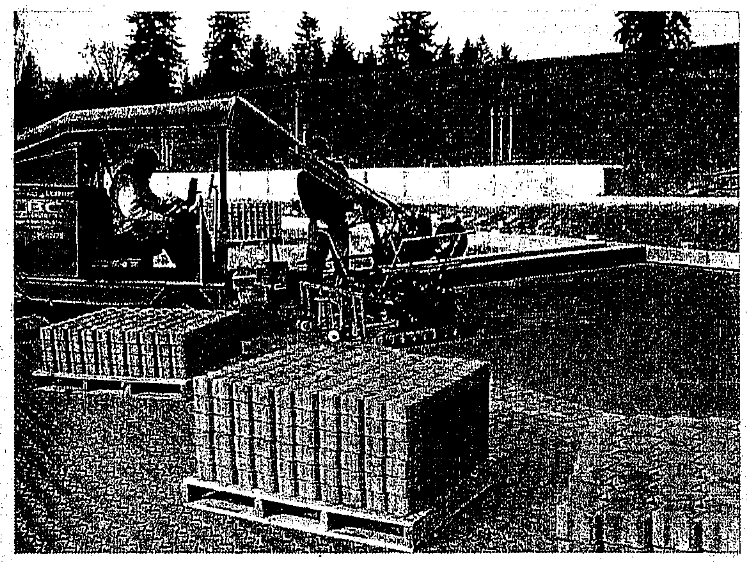


Figure 6.3.9 Mechanical installation of Eco-Stone pavers.
Photo by Curtis Hinman

- Do not compact within 3 feet of unrestrained edges (Pentec Environmental, 2000).
- Sand placed in paver openings or used as a leveling course will clog and should not be applied for those purposes.
- Cast-in-place or pre-cast concrete (approximately 6 inches wide by 12 inches high) are the preferred material for edge constraints. Plastic edge confinement secured with spikes is not recommended (Smith, 2000).

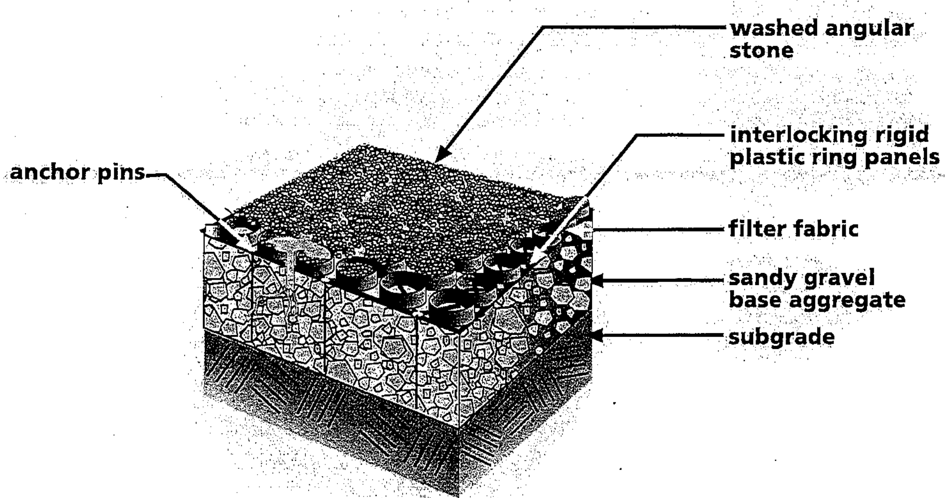
Cost

Eco-Stone material and installation costs range from $2.50 to $4.50 per square foot for the pavers, aggregate leveling layer, aggregate for the paver openings and joints, and installation. Costs for base aggregate will vary significantly depending on stormwater storage needs. Base material and installation, geotextile, excavation, and sediment controls are not included in this price estimate. Large jobs (e.g., 150,000 square feet) utilizing mechanical placement of pavers would qualify for the lower end of the cost range and smaller jobs (e.g., 40,000 square feet) with mechanical installation would likely be at the higher end of the cost range (personal communication, Brian Crooks and Dave Parisi, July 2004).

4. Gravelpave2 flexible plastic grid system

Gravelpave2 is a lightweight grid of plastic rings in 20" wide x 20" long x 1" high units with a geotextile fabric heat fused to the bottom of the grid. The grid and fabric is provided in pre-assembled rolls of various dimensions (Invisible Structures, 2003). This and other similar plastic grid systems have a large amount of open cell available for infiltration in relation to the solid support structure. Flexible grid systems conform to the grade of the aggregate base, and when backfilled with appropriate aggregate top course, provide high load bearing capability (Gravelpave2 load capacity is approximately 5700 psi) (Invisible Structures, 2003). Gravelpave2 is not impacted by the degree of freeze-thaw conditions found in the Puget Sound region. Properly installed and maintained, Gravelpave2 has an expected service life of approximately 20 years (Bohnhoff, 2001).

Figure 6.3.10 Gravelpave2 System.
Graphic by Gary Anderson



Design

Application: Typical uses include alleys, driveways, utility access, loading areas, trails, and parking lots with relatively low traffic speeds (15 to 20 mph maximum). Higher speeds may require use of a binder at 10 percent cement by weight with fill stone (Bohnhoff, 2001).

Soil infiltration rate

- If runoff is not directed to the Gravelpave system from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.5 inch/hour. Soils with lower infiltration rates should have under-drains in the base course to prevent prolonged saturated soil conditions within the top course section.
- Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. Surface flows from adjacent areas can introduce excess sediment, increase clogging, and result in excessive hydrologic loading. However, it may be acceptable to direct flows after treatment to the subgrade if storage volume and infiltration rates allow.

Subgrade

- Soil conditions should be analyzed for load bearing given anticipated soil moisture conditions by a qualified engineer.
- After grading, the existing subgrade should not be compacted or subject to excessive construction equipment traffic.
- Immediately before base aggregate and top course, remove any accumulation of fine material from erosion with light equipment.

Aggregate base/storage bed

- Minimum base thickness depends on vehicle loads, soil type, and stormwater storage requirements. Typical minimum depth is 4 to 6 inches for driveways, alleys, and parking lots (less base course depth is required for trails) (personal communication, Andy Gersen, July 2004). Increased depths can be applied for increased storage capacity.

- Base aggregate is a sandy gravel material typical for road base construction (Invisible Structures, 2003).

Aggregate grading:	U.S. Standard Sieve	Percent Passing
	3/4	100
	3/8	85
	4	60
	8	15
	40	30
	200	<3

Base course installation

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- If using the base course for retention in parking areas, excavate storage bed level to allow even distribution of water and maximize infiltration across entire parking area.
- Install approved non-woven filter fabric to bottom and sides of excavation according to manufacturer's specifications. Where the installation is adjacent to conventional paving surfaces, the filter fabric should be wrapped up the sides and to the top of base aggregate to prevent migration of fines from the densely graded base to the open graded base aggregate, maintain proper compaction, and avoid differential settling.
- Overlap adjacent strips of fabric at least 24 inches. Secure fabric 4 feet outside of storage bed to reduce sediment input to bottom of area storage reservoir.
- Install aggregate in 6-inch lifts maximum.
- Compact each lift to 95 percent modified proctor.

Top course aggregate

Aggregate should be clean, washed angular stone with a granite hardness.

Aggregate grading:	U.S. Standard Sieve	Percent Passing
	4	100
	8	80
	16	50
	30	30
	50	15
	100	5

Top course installation

- Grid should be installed immediately after base preparation to minimize introduction of sediment and to reduce the displacement of base material from ongoing activity.
- Place grid with rings up and interlock male/female connectors along unit edges.
- Install anchors at an average rate of 6 pins per square meter. Higher speed and transition areas (for example where vehicles enter a parking lot with a plastic grid system from an asphalt road) or where heavy vehicles execute tight turns will require additional anchors (double application of pins).
- Aggregate should be back dumped to a minimum depth of 6 inches so that delivery vehicle exits over aggregate. Sharp turning on rings should be avoided.

- Spread gravel using power brooms, flat bottom shovels or wide asphalt rakes. A stiff bristle broom can be used for finishing.
- If necessary, aggregate can be compacted with a plate compactor to a level no less than the top of the rings or no more than 0.25 inch above the top of the rings (Invisible Structures, 2003).
- Provide edge constraints along edges that may have vehicle loads (particularly tight radius turning). Cast-in-place or pre-cast concrete edging is preferred.

6.3.3 Maintenance

The following provides maintenance recommendations applicable to all permeable paving surfaces.

- Erosion and introduction of sediment from surrounding land uses should be strictly controlled after construction by amending exposed soil with compost and mulch, planting exposed areas as soon as possible, and armoring outfall areas.
- Surrounding landscaped areas should be inspected regularly and possible sediment sources controlled immediately.
- Clean permeable paving surfaces to maintain infiltration capacity once or twice annually following maintenance recommendations under each paving type.
- Utility cuts should be backfilled with the same aggregate base used under the permeable paving to allow continued conveyance of stormwater through the base, and to prevent migration of fines from the standard base aggregate to the more open graded permeable base material (Diniz, 1980).

The following provides maintenance recommendations for specific permeable paving surfaces.

- Permeable asphalt and concrete
  - o Clean surfaces using suction, sweeping with suction or high-pressure wash and suction (sweeping alone is minimally effective). Street cleaning equipment using high-pressure wash with suction provides the best results on asphalt and concrete for improving infiltration rates. However, there are currently no high-pressure wash and suction machines for cleaning pavement in the U.S. The city of Olympia will be importing the first machine of this type and expects delivery early 2005 (personal communication, Mark Blosser, July 2004). Hand held pressure washers are effective for cleaning void spaces and appropriate for smaller areas such as sidewalks.
  - o Small utility cuts can be repaired with conventional asphalt or concrete if small batches of permeable material are not available or are too expensive.
- Eco-Stone permeable pavers
  - o Washing should not be used to remove debris and sediment in the openings between the pavers. Sweeping with suction can be applied to paver openings when surface and debris are dry. Vacuum settings may have to be adjusted to prevent excess uptake of aggregate from paver openings or joints (Smith, 2000).
  - o Pavers can be removed individually and replaced when utility work is complete.
  - o Replace broken pavers as necessary to prevent structural instability in the surface.

- The structure of the top edge of the paver blocks reduces chipping from snowplows. For additional protection, skids on the corner of plow blades are recommended.

- Gravelpave2
  - Remove and replace top course aggregate if clogged with sediment or contaminated (vacuum trucks for stormwater collection basins can be used to remove aggregate).
  - Remove and replace grid segments where three or more adjacent rings are broken or damaged.
  - Replenish aggregate material in grid as needed.
  - Snowplows should use skids to elevate blades slightly above the gravel surface to prevent loss of top course aggregate and damage to plastic grid.

6.3.4 Limitations

Permeable paving materials are not recommended where:

- Excessive sediment is deposited on the surface (e.g., construction and landscaping material yards).
- Steep erosion prone areas that are likely to deliver sediment and clog pavement are upslope of the permeable surface.
- Concentrated pollutant spills are possible such as gas stations, truck stops, and industrial chemical storage sites.
- Seasonally high groundwater creates prolonged saturated conditions at or near ground surface and within the pavement section.
- Fill soils can become unstable when saturated.
- Maintenance is unlikely to be performed at appropriate intervals.
- Sealing of surface from sealant application or other uncontrolled use is likely. Residential driveways can be particularly challenging and clear, enforceable guidelines, education, and backup systems should be part of the stormwater management plan for a residential area utilizing permeable paving for driveways.
- Regular, heavy application of sand is used for maintaining traction during winter.
- Permeable paving should not be placed over solid rock without an adequate layer of aggregate base.

Slope restrictions result primarily from flow control concerns and to a lesser degree structural limitations of the permeable paving. Excessive gradient increases surface and subsurface flow velocities and reduces storage and infiltration capacity of the pavement system. Baffle systems placed on the subgrade can be used to detain subsurface flow and increase infiltration (personal communication, Tracy Tackett). See Chapter 7 for the flow control credit associated with permeable paving and subgrade baffles.

- Permeable asphalt is not recommended for slopes exceeding 5 percent.
- Permeable concrete is not recommended on slopes exceeding 6 percent.
- Eco-Stone is not recommended for slopes exceeding 10 percent.
- Gravelpave2 is not recommended for slopes exceeding 6 percent (primarily a traction rather than infiltration or structural limitation).

6.3.5 Permeable Paving Performance

Infiltration

Initial research indicates that properly designed and maintained permeable pavements can virtually eliminate surface flows for low intensity storms common in the Pacific Northwest, store or significantly attenuate subsurface flows (dependent on underlying soil and aggregate storage design), and provide water quality treatment for nutrients, metals, and hydrocarbons. A six-year University of Washington permeable pavement demonstration project found that nearly all water infiltrated various test surfaces (included Eco-Stone, Gravelpave, and others) for all observed storms (Brattebo and Booth, 2003). Observed infiltration was high despite minimal maintenance conducted. See Figure 6.3.11 for infiltration plotted with precipitation for one of the permeable paving test surfaces (turfstone).

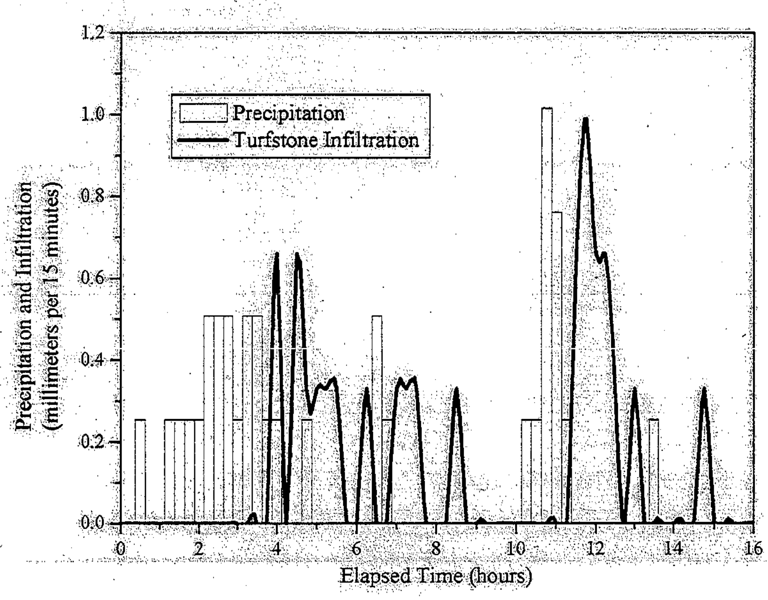


Figure 6.3.11 Infiltration plotted with precipitation at a test permeable pavement parking stall in the city of Renton. Note that essentially all precipitation infiltrates.
Source: Brattebo and Booth, 2003

Initial infiltration rates for properly installed permeable pavement systems are high. Infiltration rates for in-service surfaces decline to varying degrees depending on numerous factors, including initial design and installation, sediment loads, and maintenance. Ranges of new and in-service infiltration rates for research cited in the Appendix 7: Porous Paving Research are summarized below. To provide context for the infiltration rates below, typical rainfall rates are approximately 0.05 inch/hour in the Puget Sound region with brief downpours of 1 to 2 inches/hour.

Porous asphalt:	highest initial rate (new installation): 1750 in/hr lowest initial rate (new installation): 28 in/hr highest in-service rate: 1750 in/hr (1 year of service, no maintenance) lowest in-service rate: 13 in/hr (3 years of service no maintenance)
Pervious concrete:	highest initial rate: 1438.20 in/hr lowest in-service rate: 240 in/hr (6.5 years of service, no maintenance) Note: City of Olympia has observed (anecdotal) evidence of lower infiltration rates on a sidewalk application; however, no monitoring data have been collected to quantify observations (personal communication Mark Blosser, August 2004).

Pervious pavers: highest initial infiltration rate (new installation): none reported
lowest initial rate (new installation): none reported
highest in-service rate: 2000 in/hr
lowest in-service rate: 0.58 in/hr

Clogging from fine sediment is a primary mechanism that degrades infiltration rates. However, the design of the porous surface (i.e., percent fines, type of aggregate, compaction, asphalt density, etc.) is critical for determining infiltration rates and performance over time as well.

Various levels of clogging are inevitable depending on design, installation, and maintenance and should be accounted for in the long-term design objectives. Studies reviewed in the Porous Paving Research (see Appendix 7) and a review conducted by St. John (1997) indicate that a 50 percent infiltration rate reduction is typical for permeable pavements.

European research examining several permeable paver field sites estimates a long-term design rate at 4.25 inches per hour (Borgwardt, 1994). David Smith from Interlocking Concrete Pavement Institute, however, recommends using a conservative 1.1-inch per hour infiltration rate for the base course (surface intake can be higher) for the typical 20-year life span of permeable paver installations (Smith, 2000).

The lowest infiltration rate reported for an in-service permeable paving surface that was properly installed was approximately 0.58 inches/hour (Uni Eco-Stone parking installation).

Results from the three field studies evaluating cleaning strategies indicate that infiltration rates can be restored. Pervious paver research in Ontario, Canada indicates that infiltration rates can be maintained for Eco-Stone with suction equipment (see Appendix 7: Porous Paving Research). Standard street cleaning equipment with suction may need to be adjusted to prevent excessive uptake of aggregate in paver cells (Gerrits and James, 2001). Washing should not be used to remove debris and sediment in the openings between pavers. Suction should be applied to paver openings when surface and debris are dry.

Street cleaning equipment with sweeping and suction perform adequately on moderately degraded porous asphalt while high pressure washing with suction provides the best performance on highly degraded asphalt (Dierkes, Kuhlmann, Kandasamy and Angelis, 2002 and Balades, Legret and Madiec, 1995). Sweeping alone does not improve infiltration on porous asphalt.

Water Quality

Research indicates that the pollutant removal capability of permeable paving systems is very good for constituents examined. Laboratory evaluation of aggregate base material in Germany found removal capability of 89 to 98 percent for lead, 74 to 98 percent for cadmium, 89 to 96 percent for copper, and 72 to 98 percent for zinc (variability in removal rates depended on type of stone). The same study excavated a 15-year old permeable paver installation in a commercial parking lot and found no significant concentrations of heavy metals, no detection of PAHs, and elevated, but still low concentrations of mineral oil in the underlying soil (Dierkes et al., 2002).

Pratt, Newman and Bond recorded a 97.6 percent removal of automobile mineral oil in a 780 mm (approximately 31-inch) deep permeable paver section in England. Removal was attributed largely to biological breakdown by microbial activity within the pavement section, as well as adhesion to paving materials (Pratt, Newman and Bond, 1999).

A study in Connecticut compared driveways constructed from conventional asphalt and permeable pavers (UNI group Eco-Stone) for runoff depth (precipitation measured on-site), infiltration rates, and pollutant concentrations. The Eco-Stone driveways were two years old. During 2002 and 2003, mean weekly runoff depth recorded for asphalt was 1.8 mm compared to 0.5mm for the pavers. Table 6.3.1 summarizes pollutant concentrations from the study (Clausen and Gilbert, 2003).

Table 6.3.1 Mean weekly pollutant concentration in stormwater runoff, Jordan Cove, CT.

Variable	Asphalt	Paver
TSS	47.8 mg/L	15.8 mg/L
NO_3-N	0.6 mg/L	0.2 mg/L
NH_3-N	0.18 mg/L	0.05 mg/L
TP	0.244 mg/L	0.162 mg/L
Cu	18 ug/L	6 ug/L
Pb	6 ug/L	2 ug/L
Zn	87 ug/L	25 ug/L

(Adapted from Clausen and Gilbert, 2003)

In the Puget Sound region, a six-year permeable parking lot demonstration project conducted by the University of Washington found toxic concentrations of copper and zinc in 97 percent of the surface runoff samples from an asphalt control parking stall. In contrast, copper and zinc in 31 of 36 samples from the permeable parking stall–that produced primarily subsurface flow–fell below toxic levels and a majority of samples fell below detectable levels. Motor oil was detected in 89 percent of the samples from the surface flow off the asphalt stall. No motor oil was detected in any samples that infiltrated through the permeable paving sections. (Brattebo and Booth, 2003).

6.4 Vegetated Roofs

Vegetated roofs (also known as green roofs and eco-roofs) fall into two categories: intensive and extensive. Intensive roofs are designed with a relatively deep soil profile (6 inches and deeper) and are often planted with ground covers, shrubs, and trees. Intensive green roofs may be accessible to the public for walking or serve as a major landscaping element of the urban setting. Extensive vegetated roofs are designed with shallow, light-weight soil profiles (1 to 5 inches) and ground cover plants adapted to the harsh conditions of the roof top environment. This discussion focuses on the extensive design.

Vegetated roofs improve energy efficiency and air quality, reduce temperatures and noise in urban areas, improve aesthetics, extend the life of the roof, and reduce stormwater flows.

Extensive green roofs offer a number of benefits in the urban landscape including: increased energy efficiency, improved air quality, reduced temperatures in urban areas, noise reduction, improved aesthetics, extended life of the roof, and central to this discussion, improved stormwater management (Grant, Engleback and Nicholson, 2003).

Companies specializing in vegetated roof installations emerged in Germany and Switzerland in the late 1950s, and by the 1970s extensive green roof applications were common in those countries. In 2003, 13.5 million square meters of green roofs were installed in Germany (Grant et al., 2003; Peck, Callaghan, Kuhn and Bass, 1999; and Peck, Kuhn and Arch, n.d.). While roof gardens are not as prevalent in the U.S., designers in North America are discovering the value of the technology and green roofs are becoming more common with installations on large buildings and individual residences in Portland, Philadelphia, Chicago, Seattle, and other cities.

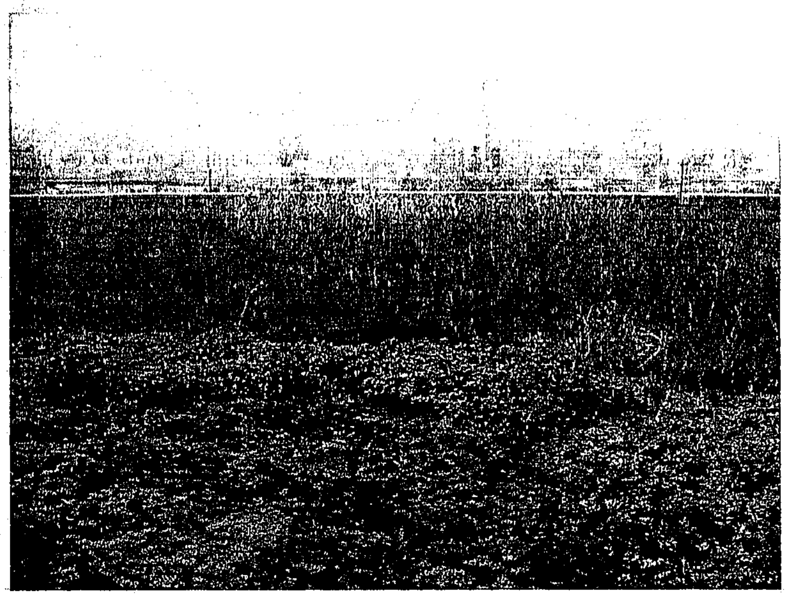


Figure 6.4.1 Vegetated roof on the Multnomah County building in Portland, Oregon.
Photo by Erica Guttman

6.4.1 Applications

Initial vegetated roof installations in the 1970s were prone to leaking. New technologies and installation techniques have improved and essentially eliminated past problems. Green roofs can be installed on almost any building with slopes up to 40 degrees and are effective strategies for managing stormwater in highly urbanized settings where rooftops comprise a large percentage of the total impervious surface (Scholtz-Barth, 2001).

6.4.2 Design

Native soils are heavy and would exert unnecessarily heavy loads for an extensive green roof installation, particularly when wet. Extensive roofs utilize light-weight soil mixes to reduce loads. Installations often range from 1 to 6 inches in depth and research from Germany indicates that, in general, a 3-inch soil depth offers the best environmental and aesthetic benefit to cost ratio (Miller, 2002).

While roof gardens can be installed on slopes up to 40 degrees, slopes between 5 and 20 degrees (1:12 and 5:12) are most suitable, and can provide natural drainage by gravity (depending on design, sloped roofs may also require a drainage layer). Flat roofs require a drainage layer to move water away from the root zone and the waterproof membrane. Roofs with slopes greater than 20 degrees require a lath grid to hold the soil substrate and drainage aggregate in place (Scholtz-Barth, 2001).

Vegetated roofs are comprised of four basic components: waterproofing membrane, drainage layer, growth medium, and vegetation. (See Figure 6.4.2 for a typical cross-section of a green roof.)

Waterproof membranes are made from PVC, Hypolan, rubber (EPDM) or polyolifins. Sixty to 80-mil reinforced PVC with heat sealed seams provides a highly durable and waterproof membrane. EPDM seams must be glued and may be more susceptible to leakage. Thermoplastic polyolifins are currently not well tested in the U.S., and U.S. manufacturers use bromides in the manufacturing process as a fire retardant which may interfere with long-term performance. Asphalt-based roofing material should be covered with high-density polyethylene membrane to prevent roots and other organisms from utilizing the organic asphalt as an energy source (Scholtz-Barth, 2001). Some membranes are not compatible with asphalt-based or other roofing materials. Follow manufacturer's recommendations for material compatibility.

The *drain layer* consists of either aggregate and/or a manufactured material that provides channels designed to transmit water at a specific rate. This layer can include a separation fabric, which with the drainage layer, reduces moisture contact with the waterproof membrane and provides additional protection from root penetration (Peck et al., n.d.).

The light-weight growth medium is designed to support plants and infiltrate and store water at a specific rate. The growth medium typically has a high mineral to organic material content and can be a mixture of various components including: gravel, sand, crushed brick, pumice, perlite, encapsulated Styrofoam, compost, and soil (Peck et al., n.d.). Saturated loads of 15 to 50 pounds/square foot are typical for extensive roofs with 1- to 5-inch soil depths (Scholtz-Barth, 2001). Currently, vegetated roofs weighing 15 pounds/square foot (comparable to typical gravel ballast roofs) have been installed and are functioning in the U.S. At 15 to 50 pounds, many roofs can be retrofitted with no or minimal reinforcement. Separating the growth medium from the building perimeter and roof penetrations with a non-combustible material (e.g., gravel) can provide increased protection against spread of fire, easier access to flashing and membrane connections, and additional protection from root penetration (Peck et al., n.d.).

Vegetation is typically succulents, grass, herbs, and/or wildflowers adapted to harsh conditions (minimal soils, seasonal drought, high winds, and strong sun exposure—i.e., alpine conditions) prevalent on rooftops. Plants should be adapted or native to the installation area. Some examples of species include: sempervivum, sedum, creeping thyme, allium, phloxes, and anntenaria. (Scholtz-Barth, 2001). Plants can be installed as vegetated mats, individual plugs, spread as cuttings, or by seeding. Vegetated mats and plugs provide the most rapid establishment for sedums. Cuttings spread over the substrate are slower to establish and will likely have a high mortality rate; however, this is a good method for increasing plant coverage on a roof that is in the process of establishing a plant community (Scholtz-Barth, 2001). During the plant establishment period soil erosion can be reduced by using a biodegradable mesh blanket.

A bonus for eco-roofs

The city of Portland encourages the application of eco-roofs in the central city to reduce stormwater runoff. Buildings using eco-roofs can earn bonus floor area (exceeding maximum floor area ratios) depending on the extent of coverage. For example, if the total area of the eco-roof is at least 60 percent of the building's footprint, each square foot of eco-roof earns three square feet of additional floor area.

Flow modeling guidance

See Chapter 7 for flow modeling guidelines for vegetated roofs when using WWHM.

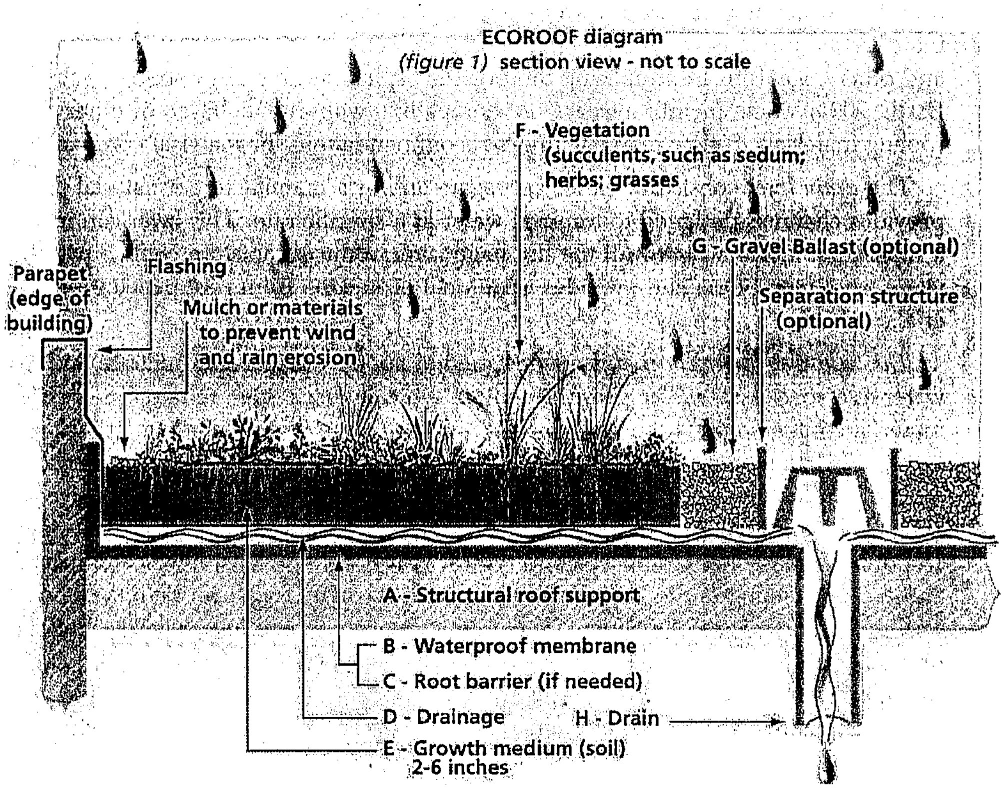


Figure 6.4.2 Cross section of vegetated roof garden. © *Environmental Services, Portland, Oregon*

For a sample vegetated roof specification, see Appendix 9.

6.4.3 Maintenance

Proper maintenance and operation are essential to ensure that designed performance and benefits continue over the full life cycle of the installation. Each roof garden installation will have specific design, operation, and maintenance guidelines provided by the manufacturer and installer. The following guidelines provide a general set of standards for prolonged roof garden performance. Note that some maintenance recommendations are different for extensive versus intensive roof gardens. The procedures outlined below are focused on extensive roof systems and different procedures for intensive roof recommendations are noted.

Schedule

- All facility components, including structural components, waterproofing, drainage layers, soil substrate, vegetation, and drains should be inspected for proper operation throughout the life of the roof garden.
- The property owner should provide the maintenance and operation plan, and inspection schedule.
- All elements should be inspected twice annually for extensive installations and four times annually for intensive installations.
- The facility owner should keep a maintenance log recording inspection dates, observations, and activities.
- Inspections should be scheduled to coincide with maintenance operations and with important horticultural cycles (e.g., prior to major weed varieties dispersing seeds).

Structural and drainage components

- Structural and drainage components should be maintained according to manufacturer's requirements and accepted engineering practices.
- Drain inlets should provide unrestricted stormwater flow from the drainage layer to the roof drain system unless the assembly is specifically designed to impound water as part of an irrigation or stormwater management program:
    - Clear the inlet pipe of soil substrate, vegetation or other debris that may obstruct free drainage of the pipe. Sources of sediment or debris should be identified and corrected.
    - Inspect drain pipe inlet for cracks, settling and proper alignment, and correct and re-compact soils or fill material surrounding pipe if necessary.
- If part of the roof design, inspect fire ventilation points for proper operation.

Vegetation Management

- The vegetation management program should establish and maintain a minimum of 90 percent plant coverage on the soil substrate.
- During regularly scheduled inspections and maintenance, bare areas should be filled in with manufacturer recommended plant species to maintain the required plant coverage.
- Normally, dead plant material will be recycled on the roof; however specific plants or aesthetic considerations may warrant removing and replacing dead material (see manufacturer's recommendations).
- Invasive or nuisance plants should be removed regularly and not allowed to accumulate and exclude planted species. At a minimum, schedule weeding with inspections to coincide with important horticultural cycles (e.g., prior to major weed varieties dispersing seeds).
- Weeding should be done manually and without herbicide applications.
- Extensive roof gardens should be designed to not require fertilization after plant establishment. If fertilization is necessary during plant establishment or for plant health and survivability after establishment, use an encapsulated, slow release fertilizer (excessive fertilization can contribute to increased nutrient loads in the stormwater system and receiving waters).
- Intensive green roofs installations require fertilization. Follow manufacturer and installer recommendations.
- Avoid application of mulch on extensive roof gardens. Mulch should be used only in unusual situations and according to the roof garden provider guidelines. In conventional landscaping mulch enhances moisture retention; however, moisture control on a vegetated roof should be through proper soil/growth media design. Mulch will also increase establishment of weeds.

Irrigation

- Surface irrigation systems on extensive roof gardens can promote weed establishment and root development near the drier surface layer of the soil substrate, and increase plant dependence on irrigation. Accordingly, subsurface irrigation methods are preferred. If surface irrigation is the only method available, use drip irrigation to deliver water to the base of the plant.
- Extensive roof gardens should be watered only when absolutely necessary for plant survival. When watering is necessary (i.e., during early plant

establishment and drought periods), saturate to the base of the soil substrate (typically 30 to 50 gallons per 100 square feet) and allow the soil to dry completely.

Operation and Maintenance Agreements

- Written guidance and/or training for operating and maintaining roof gardens should be provided along with the operation and maintenance agreement to all property owners and tenants.

Contaminants

- Measures should be taken to prevent the possible release of pollutants to the roof garden from mechanical systems or maintenance activities on mechanical systems.
- Any cause of pollutant release should be corrected as soon as identified and the pollutant removed.

Insects

- Roof garden design should provide drainage rates that do not allow pooling of water for periods that promote insect larvae development. If standing water is present for extended periods, correct drainage problem.
- Chemical sprays should not be used.

Access and Safety

- Egress and ingress routes should be clear of obstructions and maintained to design standards.

(City of Portland, 2002 and personal communication, Charlie Miller, February 2004)

6.4.4 Cost

Costs for vegetated roofs can vary significantly due to several factors including size of installation, complexity of system, growth media depth, and engineering requirements. Costs for new construction including structural support range from $10 to $15 per square foot. Retrofit costs range from $15 to $25 per square foot (Portland Bureau of Environmental Services, 2002). While initial installation costs are higher than for conventional roof systems, they are competitive on a full life cycle basis. Vegetated roofs increase the energy efficiency of a building and significantly reduce associated cooling and heating costs. European evidence indicates that a correctly installed green roof can last twice as long as a conventional roof, thereby deferring maintenance and replacement costs (Peck et al., n.d.). The above costs do not include savings on conventional stormwater management infrastructure as a result of reduced flows from a green roof or reduced stormwater utility fees.

6.4.5 Performance

Vegetated roof designs require careful attention to the interaction between the different components of the system. **Saturated hydraulic conductivity**, porosity and moisture retention of the growth media, and **transmissivity** of the drainage layer strongly influence hydrologic performance and reliability of the design (Miller and Pyke, 1999).

Research in Europe, in climates similar to the northeastern U.S., has consistently indicated that roof gardens can reduce up to 50 percent of the annual rooftop

European research, in climates similar to the northeastern U.S., has consistently indicated that roof gardens can reduce up to 50 percent of the annual rooftop stormwater runoff.

stormwater runoff (Miller and Pyke, 1999). During a 9-month pilot test in eastern Pennsylvania, 14 and 28 square foot trays with test vegetated roof sections received a total of 44 inches of precipitation and generated 15.5 inches of runoff (runoff was negligible for storm events producing less than 0.6 inches of rainfall). The pilot section was 2.74 inches thick, including the drainage layer (USEPA, 2000b).

In Portland Oregon, a 4- to 4.5-inch eco-roof retained 69 percent of the total rainfall during a 15-month monitoring period. In the first January-to-March period (2002), rainfall retention was 20 percent and during the January-to-March (2003) period retention increased to 59 percent. The most important factors likely influencing the different retention rates are vegetation and substrate maturity, and rainfall distribution. The 2002 period was a more even rainfall distribution and the 2003 period more varied with longer dry periods between storms (Hutchison, Abrams, Retzlaff and Liptan, 2003). This supports observations by other researchers that vegetated roofs are likely more effective for controlling brief (including relatively intense) events compared to long-duration storms (Miller, 2002).

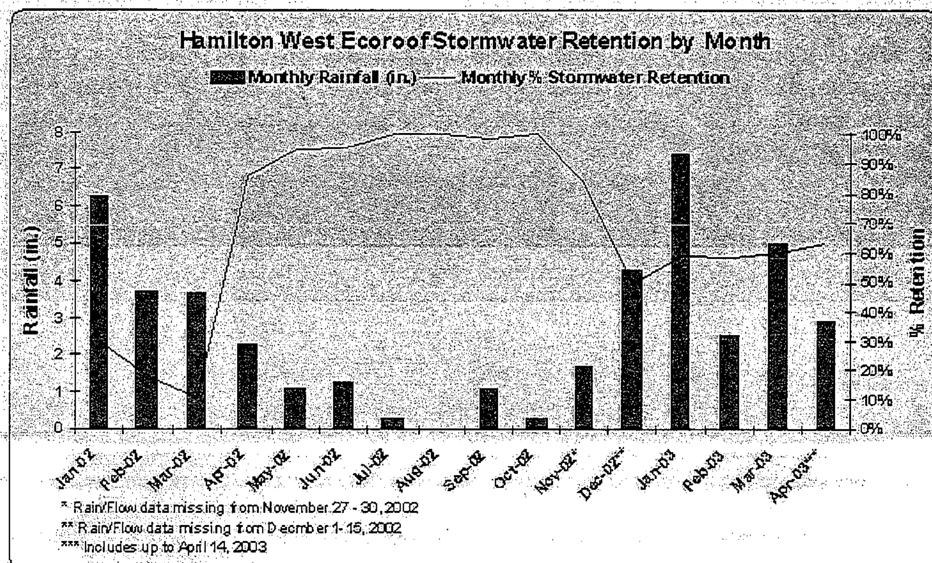


Figure 6.4.3 Precipitation and percent stormwater retained on a 4- to 4.5-inch eco-roof, Portland, OR. *Graphic from Hutchison et al., 2003*

6.5 Minimal Excavation Foundation Systems

Excavation and movement of heavy equipment during construction compacts and degrades the infiltration and storage capacity of soils. Minimal excavation foundation systems limit soil disturbance and allow storm flows to more closely approximate natural shallow subsurface flow paths. When properly dispersed into the soils adjacent to and in some cases under the foundation, roof runoff that would otherwise be directed to bioretention areas or other LID facilities can be significantly reduced.

Minimal excavation foundation systems can take many forms, but in essence are a combination of driven piles and a connection component at, or above, grade. The piles allow the foundation system to reach or engage deep load-bearing soils without having to dig out and disrupt upper soil layers, which infiltrate, store and filter stormwater flows. These piles are a more "surgical" approach to earth engineering, and may be vertical, screw-augured or angled pairs that can be made of corrosion protected steel, wood or concrete. The connection component handles

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the transfer of loads from the above structure to the piles and is most often made of concrete. Cement connection components may be pre-cast or poured on site, in continuous perimeter wall, or isolated pier configurations. For a given configuration the appropriate engineering (analyzing gravity, wind and earthquake loads) is applied for the intended structure. Several jurisdictions in the Puget Sound region have permitted minimal excavation foundations for the support of surface structures, including Pierce and King counties and the city of Olympia.

Minimal excavation foundation systems limit soil disturbance and allow storm flows to more closely approximate natural shallow subsurface flow paths under and around the foundation.

6.5.1 Applications

Minimal excavation foundations in both pier and perimeter wall configurations are suitable for residential or commercial structures up to three stories high. Secondary structures such as decks, porches, and walkways can also be supported, and the technology is particularly useful for elevated paths and foot-bridges in nature reserves and other environmentally sensitive areas. Wall configurations are typically used on flat to sloping sites up to 10 percent, and pier configurations flat to 30 percent. Some applications may be "custom" or "one-off" designs where a local engineer is employed to design a combination of conventional piling and concrete components for a specific application. Other applications may employ pre-engineered, manufactured systems that are provided by companies specifically producing low-impact foundation systems for various markets.

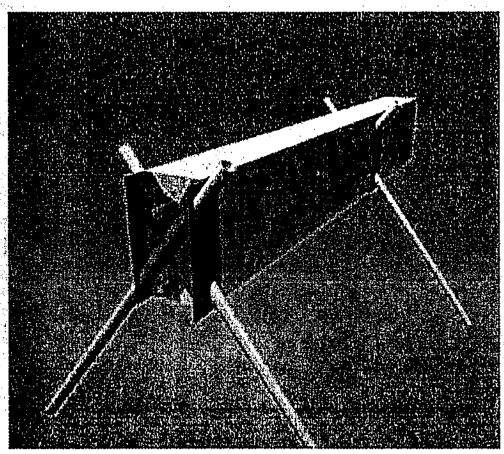


Figure 6.5.1 Typical minimal excavation foundation wall.
Graphic courtesy of Pin Foundations, Inc.

Figure 6.5.2 Building a house on Bainbridge Island using minimal excavation pier system.
Photo courtesy of R. Gagliano

The minimal excavation foundation approach can be installed on A/B and C/D soils (USDA Soil Classification) provided that the material is penetrable and will support the intended type of piles. Typical soils in the Puget Sound region, including silt loams, sandy loams, fine gravels, tight soils with clay content, and partially cemented tills are applicable. Soils typically considered problematic due to high organic content (top soils or peats) or overall bearing characteristics may often remain in place provided their depth is limited and the pins have adequate bearing in suitable underlying soils. These systems may be used on fill soils if the depth of the fill does not exceed the **reaction range** of the intended piles. Fill compaction requirements for support of such foundations may be below those of conventional development practice in some applications. In all cases, both for custom and pre-engineered systems, a qualified engineer should determine the appropriate pile and connection components, and define criteria for specific soil conditions and construction requirements.

Flow modeling guidance

See Chapter 7 for flow modeling guidelines for minimal excavation foundation systems when using the WWHM.

6.5.2 Design

Grading

In general, wall configurations require some site blading or surface terracing to accommodate the wall component itself. The lightest possible tracked equipment should be used for preparing or grading the site. Permeability of some soil types can be significantly reduced even with minimal equipment activity. Consult a qualified hydrological engineer for soil recommendations.

On relatively flat sites, blading should be limited to knocking down the highs and lows to provide a better working surface. Removing the top organic "duff" layer is not typically necessary. A free draining, compressible buffer material (pea gravel, corrugated vinyl or foam product) should be placed on surface soils to prepare the site for the placement of pre-cast or site poured wall components. This buffer material separates the base of the grade beam from surface of the soil to prevent impact from expansion or frost heave, and in some cases is employed to allow the movement of saturated flows under the wall.

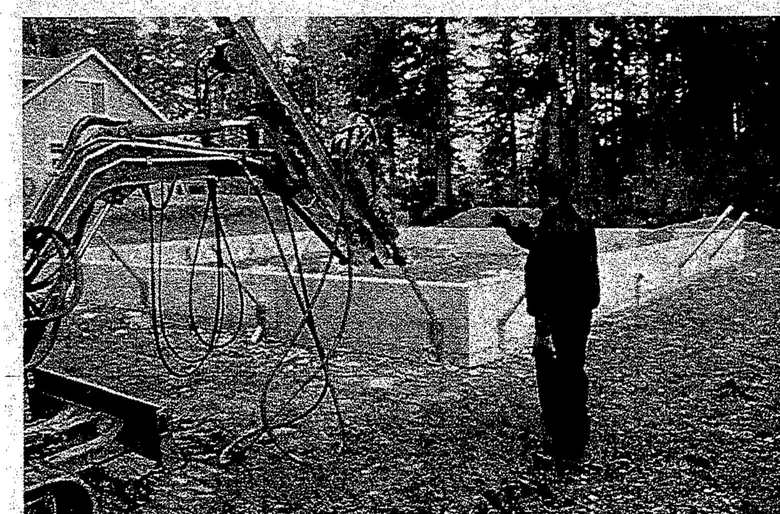


Figure 6.5.3 Minimal excavation foundation pins driven with machine-mounted automatic hammer.

Photo courtesy of R. Gagliano

On sloped sites, the soils may be bladed smooth at their existing pitch to receive pier systems, pre-cast walls with sloped bases, or slope cut forms for pouring continuous walls. Grading should be limited to knocking down the superficial highs and lows on the site to provide a better working surface only. This technique will result in the least disturbance to the upper permeable soil layers on sloped sites.

While creating more soil disturbance, the site may be terraced to receive conventional square cut forms or pre-cast walls. The height difference between terraces will be a result of the slope percentage and the width of the terrace itself. The least soil impacts will be achieved by limiting the width of each terrace to the width of the equipment blade and cutting as many terraces as possible. Some footprint designs will be more conducive to limiting these cuts, and should be considered by the architect. The terracing technique removes more of the upper permeable soil layer, and this loss should be figured into any analysis of storm flows through the site. Buffer material as described above should be used on sloping sites regardless of the grading style employed.

Additional soil may remain from foundation construction depending on grading strategy and site conditions. The material may be used to backfill the perimeter of the structure if the impacts of the additional material and equipment used to place the backfill are considered for runoff conditions.

Construction

Minimal excavation systems may be installed "pile first" or "post pile." The pile first approach involves driving or installing all the required piles in specified locations to support the structure, and then installing a connecting component (such as a formed and poured concrete grade beam) to engage the piles. Post pile methods require the setting of pre-cast or site poured components first, through which the piles are then driven. Pile first methods are typically used for deep or problematic soils where final pile depth and embedded obstructions are unpredictable. Post pile methods are typically shallower—using shorter, smaller diameter piles—and used where the soils and bearing capacities are definitive. In either case, the piles are placed at specified intervals correlated with their capacity in the soil, the size and location of the loads to be supported, and the carrying capacity of the connection component. Soil conditions are determined by geotechnical analysis. Depending on the pile system type, the size or scale of the supported structure, and the nature of the site and soils, a complete soils report including slope stability and **liquifaction** analysis may be required. For other systems a simple statement of soil properties to a limited depth, such as dry unit weight, angle of internal friction, and/or cohesive strength, may be sufficient.

The piles are driven with a machine mounted, frame mounted, or hand-held automatic hammer. The choice of driving equipment should be considered based on the size of pile and intended driving depth, the potential for equipment site impacts, and the limits of movement around the structure. Corrosion rates for buried galvanized or coated steel piling, or degradation rates for buried concrete piling, are typically low to non-existent, and piling for these types of foundations are usually considered to last the life of the structure. Special conditions such as exposure to salt air or highly caustic soils in unique built environments such as industrial zones should be considered. Wood piling typically has a more limited lifetime. Some foundation systems allow for the removal and replacement of pilings, which can extend the life of the support indefinitely.

Figure 6.5.4 Using an automatic hand-held hammer to drive pins. *Photo courtesy of R. Gagliano*

Stormwater Dispersion

Where the top or upper levels of soils have been sufficiently retained without significant loss of their permeability and storage characteristics, roof runoff and surrounding storm flows may be allowed to infiltrate without the intervention of man-made conveyance.

Where possible, roof runoff should be infiltrated uphill of the structure and across the broadest possible area. Infiltrating upslope more closely mimics natural (pre-construction) conditions by directing subsurface flows through minimally impacted soils surrounding, and in some cases, under the structure. This provides infiltration and subsurface storage area that would otherwise be lost in the construction and placement of a conventional "dug-in" foundation system. Passive gravity systems for dispersing roof water are preferred; however, active systems can be used if back-up power sources are incorporated and a consistent and manageable maintenance program is ensured.

Garage slabs, monolithic poured patios or driveways can block dispersed flows from the minimal excavation foundation perimeter, and dispersing roof runoff uphill of these areas is not recommended or must be handled with conventional means. Some soils and site conditions may not warrant intentionally directing subsurface flows directly beneath the structure, and in these cases, only the preserved soils surrounding the structure and across the site may be relied on to mimic natural flow pathways.

6.5.3 Performance

From 2000 to 2001 a minimal excavation foundation system was monitored on the Gig Harbor Peninsula. The study site was a two-story, 2300-square foot single-family residence located on a slightly sloped south facing lot with grass surrounding the house and second growth forest on the perimeter. Preparation for the foundation installation involved applying a thin layer of pea gravel directly on the existing lawn to separate the grade beam from the soil, pouring the grade beam from a pump truck, and driving steel pin piling with a hand held pneumatic hammer. The surface organic material was not removed from the construction area. Roof drains fed perforated weep hoses buried 2 to 3 inches in shallow perimeter landscape beds upslope of the house to infiltrate roof runoff and direct it along its natural pre-existing downslope path below the structure.

Soil pits were excavated around and within the foundation perimeter and gravimetric sampling was conducted to measure soil moisture content on a transect from high slope to low slope within the foundation perimeter. Relative humidity in the crawl space below the house was assessed by comparing the minimum excavation foundation system with two conventional foundation crawl spaces in the same area. The soil analysis found 2 to 6 inches of topsoil overlying a medium dense to very dense silty, fine to coarse sand with small amounts of rounded gravel. Bulk density analysis of the upper 6 inches of the soil profile found no indication of compaction after construction (0.89 to 1.46g/cc or below average to average) and the original lawn vegetation had degraded to a fine brown loam under the plastic vapor barrier in the crawl space. Soil moisture readings indicated that roof runoff was infiltrating into the soils under the house and moving downslope through the subsurface soils. At no time was water ponded above the surface, either outside or under the house. The humidity readings in the crawl space under the minimal excavation foundation system were slightly drier than the conventional crawl space, but statistically equivalent, given the variance of the monitoring equipment (Palazzi, 2002).

Additional structures installed on similar systems over the last three years, though not monitored for subsurface flows, have shown similar reductions in soil compaction impacts to the site and foundation perimeter soils.

6.6 Roof Rainwater Collection Systems

Collecting or harvesting rainwater from rooftops has been used for centuries to satisfy household, agricultural, and landscape water needs. Many systems are operating in the Puget Sound region in a variety of settings. On Marrowstone and San Juan islands, where overuse, saltwater intrusion or natural conditions limit groundwater availability, individual homes use rainwater collection for landscaping and potable supplies. In Seattle, the King Street Center building harvests approximately 1.2 million gallons of rainwater annually to supply 60 to 80 percent of the water required for flushing the building's toilets (CH2M HILL, 2001).

6.6.1 Application

Typically, rainwater collection is used where rainfall or other environmental conditions limit the availability of domestic water supply. In a low impact development, rainwater harvesting serves two purposes: water conservation and, most importantly, elimination or the large reduction of the stormwater contribution from rooftops. This practice is particularly applicable in medium to high-density development where the roof is likely to be equal to or greater than the road, driveway, and sidewalk impervious surface contribution. In the medium to high density residential setting with detached single family homes and till soil conditions, the primary LID objective of approximating pre-development hydrology is likely not feasible without reducing or eliminating the stormwater contribution from rooftops through rainwater harvesting applications.

In a low impact development, rainwater harvesting serves two purposes: water conservation and, most importantly, elimination or a large reduction of the stormwater contribution from rooftops.

Roof rainwater harvesting systems can be used in residential, commercial or industrial development for new or retrofit projects. The focus of this section is on residential applications. Rainwater harvesting technology is well developed and components readily available; however, system design and construction is relatively complex and should be provided by a qualified engineer or experienced designer.

6.6.2 Design

Collection systems should be sized according to precipitation inputs, indoor and/or outdoor water needs, and the flow reduction required to approximate pre-development hydrology. Rainwater harvesting should work in concert with other LID practices and therefore reduce the flow reduction requirements from the roof contribution and additional costs of the system.

In the Pacific Northwest the highest precipitation (supply) and lowest demand months are November to May. June through October is relatively dry and demand, driven primarily by landscape needs, is greatest during this period. To collect and remove adequate storm flows during the higher precipitation months and provide a reliable water source, large storage reservoirs or cisterns are required. Where stormwater is a primary incentive for installation and municipal or groundwater supplies are available, the rainwater collection system is installed with, and augmented by, a conventional water source.

Components of a rainwater collection system

Catchment or roof area

The roof material should not contribute contaminants (such as zinc, copper or lead) to the collection system. The National Sanitation Foundation (NSF) certifies products for rainwater collection systems. Products meeting NSF protocol P151 are certified for drinking water system use and do not contribute contaminants at levels greater than specified in the USEPA Drinking Water Regulations and Health Advisories (Stuart, 2001).

Roof materials

- Rainfall present in the Pacific Northwest is surprisingly acidic and will tend to leach materials from roofing material.
- Currently, few roof materials have been tested and the only recommendation for common roof coverings is to not use treated wood shingles or shakes.
- Metal, ceramic tile or slate are durable and smooth, presumed to not contribute significant contaminants, and are the preferred materials for potable supply. Composition or 3-tab roofing should only be used for irrigation catchment systems. Composition roofing is not recommended for irrigation supply if zinc has been applied for moss treatment.
- Lead solder should not be used for roof or gutter construction and existing roofs should be examined for lead content.
- Galvanized surfaces may deliver elevated particulate zinc during initial flushing and elevated dissolved zinc throughout a storm event (Stuart, 2001).
- Copper should never be considered for roofing or gutters. When used for roofing material, copper can act as an herbicide if rooftop runoff is used for irrigation. Copper can also be present in toxic amounts if used for a potable source.

The following general guidelines are used for calculating water production for a rainwater collection system:

- The catchment area is equal to the length times width of the guttered area (slope is not considered).

- One inch of rain falling on one square foot of rooftop will produce 0.6233 gallons of water or approximately 600 gallons per 1,000 square feet of roof without inefficiencies.
- Assume that the system will lose approximately 25 percent of the total rainfall due to evaporation, initial wetting of the collection material, and inefficiencies in the collection process (Texas Water Development Board, 1997). Precipitation loss is the least with metal, more with composition, and greatest with wood shake or shingle.

Roof washers

Roof washers collect and route the first flush away from the collection system. The first flush can contain higher levels of contaminants from particulates settling on the roof, bird droppings, etc. A simple roof washer consists of a downspout (located upstream of the downspout to the cistern) and a pipe that is fitted and sealed so that water does not back flow into the gutter. Once the pipe is filled, water flows to the cistern downspout. The pipe often extends to the ground and has a clean out and valve.

The Texas Rainwater Guide recommends that 10 gallons be diverted for every 1000 square feet of roof (applicable for areas with higher storm intensities) (Texas Water Development Board, 1997). However, local factors such as rainfall frequency, intensity, and pollutants will influence the amount of water diverted. In areas with low precipitation and lower storm intensities such as the San Juan Islands, roof washing may divert flows necessary to support system demands. Additionally, the gentle rainfall prevalent in western Washington may not be adequate to wash contaminants from the roof in the first flush. In this scenario, pre-filtration for coarse material before the storage reservoir and fine filtration (e.g., 5 microns) before disinfection is likely more effective (personal communication Tim Pope, August 2004).

Storage tank or cistern

The cistern is the most expensive component of the collection system. If the system will be used for a potable water source, the tank and any sealants and paints used in the tank should be approved by the Food and Drug Administration (FDA), USEPA or NSF. Tanks can be installed above ground (either adjacent to or remote from a structure), under a deck, or in the basement or crawl space. Above ground installations are less expensive than below ground applications. Aesthetic preferences or space limitations may require that the tank be located below ground, or away from the structure. Additional labor expenditures for excavation and structural requirements for the tank will increase costs of subsurface installations compared to above ground storage (Stuart, 2001). Multiple tank systems are generally less expensive than single tank and the multi-reservoir configurations can continue to operate if one of the tanks needs to be shut down for maintenance.

Cisterns are commonly constructed of fiberglass, polyethylene, concrete, metal, or wood. Larger tanks for potable use are available in either fiberglass for burial or corrugated, galvanized steel with PVC or Poly liners for above ground installations. Tanks should have tight fitting covers to exclude contaminants and animals, and above ground tanks should not allow penetration of sunlight to limit algae growth (Texas Water Development Board, 1997).

Figure 6.6.1 Buried tanks n San Juan Island.
hoto courtesy of Tim Pope

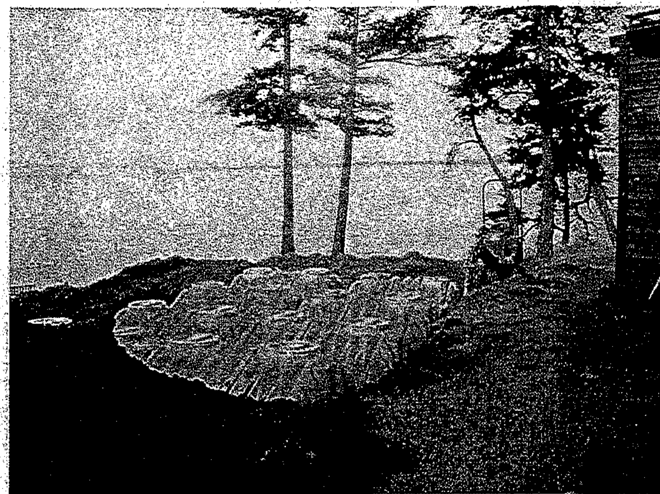


Figure 6.6.2 Collection tanks being installed under deck of a home on San Juan Island.
Photo courtesy of Tim Pope

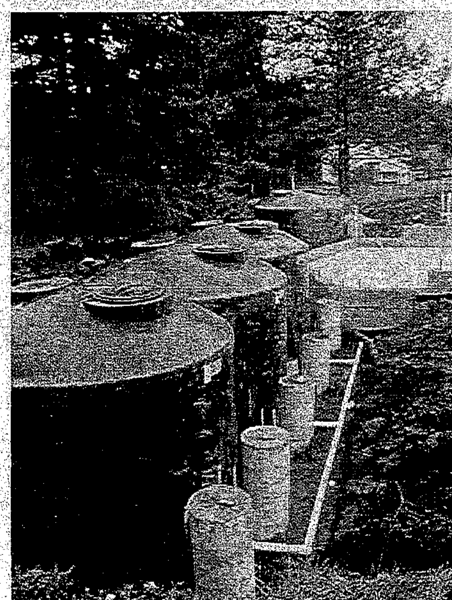


Figure 6.6.3 Collection tanks hidden under the deck of a home on San Juan Island.
Photo courtesy of Tim Pope

Figure 6.6.4 Storage tank on Lopez Island.
Photo courtesy of Tim Pope

Conveyance

Gutters are commonly made from aluminum, galvanized steel, and plastic. Rainwater is slightly acidic; accordingly, collected water entering the cistern should be evaluated for metals or other contaminants associated with the roof and gutters, and appropriate filters and disinfection techniques installed. Screens should be installed in the top of each downspout. Screens installed along the entire length of the gutter do not prevent most debris from entering the gutter; however, they can complicate cleaning. Leaf guard type gutters will exclude leaves and needles, but do not prevent pollen and dust (the most important contaminant to remove) from entering the gutter.

Unless the tank is elevated sufficiently above the point of delivery, pumps are required to provide acceptable pressure. Municipal water supply pressures are typically between 40 to 60 psi. Pressure tanks are often installed in addition to the pump to prolong the life of the pump and provide a more constant delivery pressure (Stuart, 2001).

Water treatment

Water treatment falls into three broad categories: filtration, disinfection, and buffering.

Filtration

Filters remove leaves, sediment, and other suspended particles and are placed between the catchment and the tank or in the tank. Filtering begins with screening gutter downspouts to exclude leaves and other debris and routing the first flush through roof washers, if compatible with precipitation and water needs (filtration can be incorporated with the roof washer). Types of filters for removing the smaller remaining particles include single cartridges (similar to swimming pool filters) and multi-cartridge filters (Texas Water Development Board, 1997). For potable systems, water must be filtered and disinfected after the water exits the storage reservoir and immediately before point of use.

Disinfection technologies include:

- *Ultra-violet (UV) radiation* uses short wave UV light to destroy bacteria, viruses, and other microorganisms. UV disinfection requires pre-filtering of fine particles where bacteria and viruses can lodge and elude the UV light. This disinfection strategy should be equipped with a light sensor and a readily visible alert to detect adequate levels of UV light (Texas Water Development Board, 1997).

- *Ozone* is a form of oxygen produced by passing air through a strong electrical field. Ozone kills microorganisms and oxidizes organic material to CO_2 and water. The remaining ozone reverts back to dissolved O_2 (Texas Water Development Board, 1997). Care must be exercised in the choice of materials used in the system using this disinfection technique due to ozone's aggressive properties.
- *Activated carbon* removes chlorine and heavy metals, objectionable tastes, and most odors.
- *Membrane technologies* include reverse osmosis and nano-filtration and are used primarily to filter dissolved materials such as salts or metals.
- *Chlorine* (commonly in the form of sodium hypochlorite) is a readily available and dependable disinfection technique. Household bleach can be applied in the cistern or feed pumps that release small amounts of solution while the water is pumped (Texas Water Development Board, 1997). There are two significant limitations of this technique: chlorine leaves an objectionable taste (which can be removed with activated charcoal); and prolonged presence of chlorine with organic matter can produce chlorinated organic compounds (e.g., trihalomethanes) that can present health risks (Texas Water Development Board, 1997).

Buffering

As stated previously, rainwater is usually slightly acidic (a pH of approximately 5.6 is typical). Total dissolved salts and minerals are low in precipitation and buffering with small amounts of a common buffer, such as baking soda, can adjust collected rainwater to near neutral (Texas Water Development Board, 1997). Buffering should be done each fall after tanks have first filled.

6.6.3 Barriers to Implementation

Two factors present the largest barriers to implementing rainwater harvesting:

1. **Regulatory**

   Authorizing agencies for rainwater collection include the Washington Department of Health, Ecology, and the local jurisdiction. The Department of Health does not recommend rainwater harvesting for potable supplies; however, there are no laws restricting the practice other than appropriate pollutant level criteria for human consumption. The USEPA classifies roof water collection as a surface water system and requires that the water be filtered to federal standards if for potable use. Ecology technically requires that all systems collecting surface water for consumption apply for a water right. Currently, Ecology is not enforcing its authority over roof collection for small systems (e.g., individual homes) (Stuart, 2001). Many local jurisdictions are not familiar with or restrict rainwater harvesting from roofs. In most locations, installing these systems will require special permit considerations.

2. **Cost**

   Roof water harvesting systems can add significant costs to residential construction. Systems that provide adequate storage for reliable indoor use and detain sufficient precipitation require large storage tanks, filtration and disinfection. In the example provided in Section 6.6.5: Performance, the system (10,000 gallon storage capacity for supplying toilets and clothes washing) added approximately $8,000/home to the construction costs. Roof water harvesting systems can, on the other hand, provide cost savings. New stormwater management requirements will increase infrastructure costs on challenging sites with medium to high density zoning and soils with low infiltration rates. Much, if not all, of the additional costs associated with a rainwater collection system may be offset by reducing conventional conveyance and pond infrastructure and expenditures. Building owners who use a rainwater harvest system will also reduce monthly expenses by significantly reducing their water bills.

6.6.4 Maintenance

Maintenance requirements for rainwater collection systems include typical household and system specific procedures. All controls, overflows and cleanouts should be readily accessible and alerts for system problems should be easily visible and audible. The following procedures are operation and maintenance requirements recorded with the deed of homes using roof water harvesting systems in San Juan County (personal communication, Tim Pope, August 2004).

- Debris should be removed from the roof as it accumulates.
- Gutters should be cleaned as necessary (for example in September, November, January, and April. The most critical cleaning is in mid to late-spring to flush the pollen deposits from surrounding trees.
- Screens at the top of the downspout should be maintained in good condition.
- Pre-filters should be cleaned monthly.
- Filters should be changed every six months or as pressure drop is noticed.
- UV units should be cleaned every six months and the bulb should be replaced every 12 months (or according to manufacturer's recommendation).
- Storage tanks should be chlorinated quarterly to 0.2ppm to 0.5ppm at a rate of 1/4 cup of household bleach (5.25 percent solution) to 1,000 gallons of stored water.
- Storage tanks should be inspected and debris removed periodically as needed.
- When storage tanks are cleaned, the inside surface should be rinsed with a chlorine solution of 1 cup bleach to 10 gallons water.
- When storage tanks are cleaned, the carbon filter should be removed and all household taps flushed until chlorine odor is noticed. Chlorinated water should be left standing in the piping for 30 minutes. Replace the carbon filter and resume use of the system.

6.6.5 Performance

In 2001, CH2M HILL performed an LID study on a 24-acre subdivision with 103 lots in Pierce County (CH2M HILL, 2001). The site was selected for its challenging conditions—medium density development (4 to 6 dwelling units/acre) located on a topographically closed depressional area and type C soils (USDA soils classification) with low infiltration rates. The study utilized LID principles and practices to redesign the project (on paper only) with the goal of approximating pre-development (forested) hydrologic conditions. LID practices used in the design included reducing the development envelope, minimizing impervious surfaces, increasing native soil and vegetation areas, amending disturbed soils with compost, and bioretention. Hydrologic analysis using continuous simulation (HSPF) was performed to assess the effectiveness of the selected LID practices for achieving the project goal.

The hydrologic simulations of the proposed low impact development design indicated that the goals of the project could not be achieved by site planning and reducing impervious surfaces alone while maintaining four or more dwelling units per acre. The challenging site conditions required that additional LID tools be utilized to approximate forested hydrology. Accordingly, the potential to collect and use rooftop stormwater was considered to reduce surface flows.

A 1,300-sq. ft. impervious footprint was used to reflect the compact, two-story design for the detached single-family homes. At this density the rooftop contributing to the total impervious surface in the development was almost 60 percent. Only non-potable uses such as laundry, toilet, and irrigation were investigated to reduce design costs and regulatory barriers. To estimate the storage volume required for non-potable uses, the amount of water used inside the house was first estimated. The average inside water use for homes that conserve water is approximately 49.2 gallons per person per day (Maddaus, William O., 1987, Water Conservation, American Water Works Association). Table 6.6.1 contains a breakdown of average daily water use per person/day.

Table 6.6.1 Household water use.

Type of Use	Gallons per person per day	**Percent of Total***
Showers	8.2	17
Toilets	6.4	13
Toilet leakage	4.1	8
Baths	7.0	14
Faucets	8.5	17
Dishwashers	2.4	5
Washing machines	12.6	26

* The average inside water use for homes that conserve water is approximately 49.2 gallons per person per day

The project considered using captured rainwater in toilets and washing machines. Stormwater collected from roof runoff may also be used for irrigation but because of the small lot sizes, this use was not factored into the calculation for storage requirements. However, the calculations assume that the storage system will be empty at the beginning of the wet season, so any excess stored water during the summer months should be used for irrigation.

To estimate the amount of storage required, the volume of rainfall from a 1300-sq. ft. surface was plotted over time against curves showing water usage based on a 5-gallon toilet, a 3.3-gallon toilet, a low-flow toilet (1.6 gallon), and a low-flow toilet combined with a washing machine. Monthly average rainfall for Pierce County was used (41.5 inches annually). Although the 5-gallon toilet resulted in the smallest required storage volume, new construction requires the use of low flow toilets, so the storage required for a combination low flow toilet and washing machine was used. This resulted in a required storage volume of approximately 10,000 gallons, or 1,333 cu. ft. Accounting for evaporation and other inefficiencies in the collection process, the 103 houses on the LID site would capture and use approximately 8 acre-ft of water annually.

From a hydrologic standpoint, collecting and using rooftop runoff reduces or removes the roof contribution from the surface water system. Collecting the appropriate percentage of total precipitation can simulate the amount of water that is naturally transpired and evaporated in a forested environment. As a result, the surface water system in the low impact development responds more like a forested system.

7 Washington Department of Ecology Low Impact Development Design and Flow Modeling Guidance

In this chapter...

Flow control "credits" for:

- *Permeable pavements*
- *Dispersion*
- *Vegetated roofs*
- *Rainwater harvesting*
- *Reverse slope sidewalks*
- *Minimal excavation foundations*
- *Bioretention*

The Washington Department of Ecology (Ecology) encourages the use of the Western Washington Hydrology Model (WWHM) and other approved runoff models to estimate surface runoff and size stormwater control and treatment facilities. Other currently approved models are the King County Runoff Time Series and MGS Flood. This guidance suggests how to represent various LID techniques within those models so that their benefit in reducing surface runoff can be estimated. The lower runoff estimates should translate into smaller stormwater treatment and flow control facilities. In certain cases, the use of various techniques can result in the elimination of those facilities.

An LID credit committee comprised of stormwater managers from various local jurisdictions, Washington State University Extension, and Ecology developed the flow control credits presented in this chapter. The guidance is also available through Ecology's web site as an addendum to the 2005 *Stormwater Management Manual for Western Washington* (SMMWW).

This section identifies seven categories of LID techniques. For each category, the guidance includes basic design criteria that Ecology considers necessary in order to justify use of the suggested runoff "credit" or "runoff model representation." More detailed design guidance is available in Chapter 6: Integrated Management Practices.

As the Puget Sound community gains more experience with and knowledge of LID techniques, the design criteria will evolve. Also, our ability to model their performance will change as modeling techniques improve. Therefore, we anticipate this guidance will be updated periodically to reflect new knowledge and modeling approaches. Meanwhile, we encourage all to use the guidance, and to give us feedback on its usefulness and accuracy. Comments can be sent to Ed O'Brien of Ecology at eobr461@ecy.wa.gov.

Note that the terminology for grass has changed in the WWHM. The term "grass" has been replaced with "landscaped area."

7.1 Permeable Pavements

7.1.1 Credits

7.1.1.1 Porous Asphalt or Concrete

Description of public road or public parking lot	Model Surface as
(1) Base material laid above surrounding grade:	
(a) Without underlying perforated drain pipes to collect stormwater	Landscaped area over underlying soil type (till or outwash)
(b) With underlying perforated drain pipes for stormwater collection:	
at or below bottom of base layer	Impervious surface
elevated within the base course	Impervious surface
(2) Base material laid partially or completely below surrounding grade:	
(a) Without underlying perforated drain pipes	Option 1: Landscaped area over underlying soil type Option 2: Impervious surface routed to an infiltration basin[1]
(b) With underlying perforated drain pipes:	
at or below bottom of base layer	Impervious surface
elevated within the base course[2]	Model as impervious surface routed to an infiltration basin[1]

Description of private facilities (driveways, parking lots, walks, patios)	
1. Base material below grade without underlying perforated drain pipes	50% landscaped area on underlying soil; 50% impervious
2. Base material below grade with underlying perforated drain pipes	Impervious surface

7.1.1.2 Grid/lattice Systems (Non-concrete) and Paving Blocks

Description of public road or public parking lot	Model Surface as
(1) Base material laid above surrounding grade	
(a) Without underlying perforated drain pipes	*Grid/lattice systems:* landscaped area on underlying soil (till or outwash). *Paving Blocks:* 50% landscaped area on underlying soil; 50% impervious.
(b) With underlying perforated drain pipes	Impervious surface

[1] See Section 7.8 for detailed instructions concerning how to represent the base material below grade as an infiltration basin in the Western Washington Hydrology Model.

[2] If the perforated pipes function is to distribute runoff directly below the wearing surface, and the pipes are above the surrounding grade, follow the directions for 2a above.

(2) Base material laid partially or completely below surrounding grade	
(a) Without underlying perforated drain pipes	Option 1: *Grid/lattice systems:* landscaped area on underlying soil. *Paving blocks:* 50% landscaped area; 50% impervious. Option 2: Impervious surface routed to an infiltration basin.[1]
(b) With underlying perforated drain pipes	
at or below bottom of base layer	Impervious surface
elevated within the base course[2]	Model as impervious surface routed to an infiltration basin.[1]

Description of private facilities (driveways, parking lots, walks, patios)

Base material laid partially or completely below surrounding grade	
(a) Without underlying perforated drain pipes	50% landscaped area; 50% impervious
(b) With underlying drain pipes	Impervious surface

7.1.2 Design Criteria for Permeable Pavements

Subgrade

- Compact the subgrade to the minimum necessary for structural stability. Use small static dual wheel mechanical rollers or plate vibration machines for compaction. Do not allow heavy compaction due to heavy equipment operation. The subgrade should not be subject to truck traffic.
- Use on soil types A through C.

Geotextile

- Use geotextile between the subgrade and base material/separation layer to keep soil out of base materials.
- The geotextile should pass water at a greater rate than the subgrade soils.

Separation or bottom filter layer (recommended but optional)

- A layer of sand or crushed stone (0.5 inch or smaller) graded flat is recommended to promote infiltration across the surface, stabilize the base layer, protect underlying soil from compaction, and serve as a transition between the base course and the underlying geotextile material.

Base material

- Many design combinations are possible. The material must be free draining. For more detailed specifications for different types of permeable pavement, see Section 6.3: Permeable Paving.
  - o Driveways (recommendation):
    - ✓ > 4-inch layer of free-draining crushed rock, screened gravel, or washed sand.

- ✓ < 5 percent fines (material passing through #200 sieve) based on fraction passing #4 sieve.
- o Roads: The standard materials and quantities used for asphalt roads should be followed. For example:
  - ✓ 'Pierce County cites larger rock on bottom, smaller on top (e.g., 2" down to 5/8"); compacted; minimal fines; 8 inches total of asphaltic concrete and base material.
  - ✓ Washington State Department of Transportation (WSDOT) lists coarse crushed stone aggregate (AASHTO Grading No. 57: 1.5 inch and lower); stabilized or unstabilized with modest compaction; meets fracture requirements.
  - ✓ The Federal Highway Administration suggests three layers between the porous pavement and geotextile. Typical layers would be:
    Filter course: 13 mm diameter gravel, 25 to 50 mm thick.
    Stone reservoir: 40 to 75 mm diameter stone.
    Filter course: 13 mm diameter gravel, 50 mm thick.

Wearing layer

- For all surface types, a minimum initial infiltration rate of 10 inches per hour is necessary. To improve the probability of long-term performance, significantly higher infiltration rates are desirable.
- *Porous Asphalt:* Products must have adequate void spaces through which water can infiltrate. A void space within the range of 12 to 20 percent is common.
- *Porous Concrete:* Products must have adequate void spaces through which water can infiltrate. A void space within the range of 15 to 21 percent is common.
- *Grid/lattice systems filled with gravel, sand, or a soil of finer particles with or without grass:* The fill material must be at least a minimum of 2 inches of sand, gravel, or soil. It should be underlain with 6 inches or more of sand or gravel to provide an adequate base. The fill material should be at or slightly below the top elevation of the grid/lattice structure. Modular-grid openings must be at least 40 percent of the total surface area of the modular grid pavement. Provisions for removal of oil and grease contaminated soils should be included in the maintenance plan.
- *Paving blocks:* 6 inches of sand or aggregate materials should fill spaces between blocks and must be free draining. Do not use sand for the leveling layer or filling spaces with Eco-Stone.
- The block system should provide a minimum of 12 percent free draining surface area.
- Provisions for removal of oil and grease contaminated soils should be included in the maintenance plan.

Drainage conveyance

Roads should still be designed with adequate drainage conveyance facilities as if the road surface was impermeable. Roads with base courses that extend below the surrounding grade should have a designed drainage flow path to safely move water away from the road prism and into the roadside drainage facilities. Use of perforated storm drains to collect and transport infiltrated water from under the road surface will result in less effective designs and less flow reduction credit.

Acceptance test

- Driveways can be tested by simply emptying a bucket of water on the surface. If anything other than a scant amount puddles or runs off the surface, additional testing is necessary prior to accepting the construction.
- Roads may be initially tested with the bucket test. In addition, test the initial infiltration with a 6-inch ring, sealed at the base to the road surface, or with a sprinkler infiltrometer. Wet the road surface continuously for 10 minutes. Begin test to determine compliance with 10 inches per hour minimum rate.

Limitations

- No run-on from pervious surfaces is preferred. If runoff comes from minor or incidental pervious areas, those areas must be fully stabilized.
- Slope impervious runoff away from the permeable pavement to the maximum extent practicable. Sheet flow from up-gradient impervious areas is not recommended, but permissible if porous surface flow path ≥ impervious surface flow path. Impervious surface that drains to a permeable pavement can also be modeled as noted in Section 7.1.1 as long as the flow path restriction is met.
- Do not use on "high use sites" (as defined in the 2005 SMMWW, Volume V, Section 3.2), auto commercial services (gas stations, mini-marts, commercial fueling stations, auto body and auto repair shops, auto wash), commercial truck parking areas, areas with heavy industrial activity (as defined by U.S. EPA regulations), or areas with high pesticide use.
- Soils must not be tracked onto the wear layer or the base course during construction.
- Slopes:
    - o Asphalt: Works best on level slopes and up to 2 percent. Do not use on slopes ≥ 5 percent.
    - o Concrete: Maximum recommended slope of 6 percent.
    - o Interlocking pavers: Maximum recommended slope of 10 percent.
    - o Grid/lattice systems: Maximum generally in 5 to 6 percent range.
- Do not use in areas subject to heavy, routine sanding for traction during snow and ice accumulation.
- Comply with local building codes for separation distances from buildings and wells. Inquire with the local jurisdiction concerning applicable setbacks.

Maintenance

- Inspect project upon completion to correct accumulation of fine material. Conduct periodic visual inspections to determine if surfaces are clogged with vegetation or fine soils. Clogged surfaces should be corrected immediately.
- Surfaces should be swept with a high-efficiency or vacuum sweeper twice per year; preferably once in the autumn after leaf fall and again in early spring. For porous asphalt and concrete surfaces, high-pressure hosing should follow sweeping once per year.

7.2 Dispersion

7.2.1 Full Dispersion for the Entire Development Site (fulfills treatment and flow control requirements)

Developments that preserve 65 percent of a site (or a **threshold discharge area** of a site) in a forested or native condition can disperse runoff from the developed portion of the site into the native vegetation area as long as the developed areas draining to the native vegetation do not have impervious areas that exceed 10 percent of the entire site. Runoff must be dispersed into the native area in accordance with the BMPs cited in BMP T5.30 of the 2005 SMMWW. Additional impervious areas are allowed, but should not drain to the native vegetation area and are subject to the thresholds, and treatment and flow control requirements of the stormwater manual.

7.2.2 Full Dispersion for all or Part of the Development Site

Developments that cannot preserve 65 percent or more of the site in a forested or native condition may disperse runoff into a forested or native area in accordance with the BMPs cited in BMP T5.30 of the 2005 SMMWW if:

- The effective impervious surface of the area draining into the native vegetation area is ≤ 10 percent; and
- The development maintains ratios proportional to the 65 percent forested or native condition and 10 percent effective impervious area. Examples of such ratios are:

% Native Vegetation Preserved (min. allowed)	% Effective Impervious (max. allowed)	% Lawn/Landscape (max. allowed)
65	10	35
60	9	40
55	8.5	45
50	8	50*
45	7	55*
40	6	60*
35	5.5	65*

* Where lawn/landscape areas are established on till soils, and exceed 50 percent of the total site, they should be developed using guidelines in Section 6.2: Amending Construction Site Soils or a locally approved alternative specification for soil quality and depth.

Within the context of this dispersion option, the only impervious surfaces that are ineffective are those that are routed into an appropriately sized dry well or into an infiltration basin that meets the flow control standard and does not overflow into the forested or native vegetation area.

Note: For options in 7.2.1 and 7.2.2, native vegetation areas must be protected from future development. Protection must be provided through legal documents on record with the local government. Examples of adequate documentation include a conservation easement, conservation parcel, and deed restriction.

7.2.3 Partial Dispersion on Residential Lots and Commercial Buildings

If roof runoff is dispersed on single-family lots greater than 22,000 square feet according to the design criteria and guidelines in BMP T5.10 of the 2005 SMMWW, and the vegetative flow path is 50 feet or longer through undisturbed native landscape or lawn/landscape area that meets the guidelines in Section 6.2: Amending Construction Site Soils, the roof area may be modeled as landscaped area. This is done by clicking on the "Credits" button in the WWHM and entering the percent of roof area that is being dispersed.

The vegetated flow path is measured from the downspout or dispersion system discharge point to the downstream property line, stream, wetland, or other impervious surface.

Where BMP T5.11 (concentrated flow dispersion) or BMP T5.12 (sheet flow dispersion) of the 2005 SMMWW is used to disperse runoff into a native vegetation area or an area that meets the guidelines in Section 6.2: Amending Construction Site Soils, the impervious area may be modeled as landscaped area. This can be done by entering the impervious area as landscaped area rather than entering it as impervious area.

7.2.4 Road Projects

(1) Uncollected or natural dispersion into adjacent vegetated areas (i.e., sheet flow into the dispersion area)

Full dispersion credit (i.e., no other treatment or flow control required) is given to projects that meet the following criteria:

(a) *Outwash soils* (Type A – sands and sandy gravels, possibly some Type B – loamy sands) that have an initial saturated infiltration rate of 4 inches per hour or greater. The infiltration rate must be based on one of the following: (1) A D_{10} size (10 percent passing the size listed) greater than 0.06 mm (based on the estimated infiltration rate indicated by the upper-bound line in Figure 4-17 of the WSDOT Highway Runoff Manual) for the finest soil within a three foot depth; (2) field results using procedures (Pilot Infiltration Test) identified in Appendix III-D (formerly V-B) of the 2005 SMMWW.

- 20 feet of impervious flow path needs 10 feet of dispersion area width.
- Each additional foot of impervious flow path needs 0.25 feet of dispersion area width.

(b) *Other soils:* (Types C and D and some Type B not meeting the criterion in 1(a) above)

- Dispersion area must have 6.5 feet of width for every 1-foot width of impervious area draining to it. A minimum distance of 100 feet is necessary.

(c) *Criteria applicable to all soil types:*

- Depth to the average annual maximum groundwater elevation should be at least 3 feet.
- Impervious surface flow path must be ≤ 75 ft. Pervious flow path must be ≤ 150 feet. Pervious flow paths are up-gradient road side slopes that run onto the road and down-gradient road side slopes that precede the dispersion area.

- Lateral slope of impervious drainage area should be ≤ 8 percent. Road side slopes must be ≤ 25 percent. Road side slopes do not count as part of the dispersion area unless native vegetation is re-established and slopes are less than 15 percent. Road shoulders that are paved or graveled to withstand occasional vehicle loading count as impervious surface.
- Longitudinal slope of road should be ≤ 5 percent.
- Length of dispersion area should be equivalent to length of road.
- Average longitudinal (parallel to road) slope of dispersion area should be ≤ 15 percent.
- Average lateral slope of dispersion area should be ≤ 15 percent.

(2) Channelized (collected and re-dispersed) stormwater into areas with (a) native vegetation or (b) cleared land in areas outside of urban growth areas that do not have a natural or man-made drainage system

Full dispersion credit (i.e., no other treatment or flow control required) is given to projects that meet the following criteria:

(a) *Outwash soils* (Type A – sands and sandy gravels, possibly some Type B – loamy sands) that have an initial saturated infiltration rate of 4 inches per hour or greater. The infiltration rate must be based on one of the following: (1) A D_{10} size (10% passing the size listed) greater than 0.06 mm (based on the estimated infiltration rate indicated by the upper-bound line in Figure 4-17 of the WSDOT Highway Runoff Manual) for the finest soil within a 3-foot depth; 2 field results using procedures (Pilot Infiltration Test) identified in Appendix III-D (previously V-B) of the 2005 SMMWW.

- Dispersion area should be at least ½ of the impervious drainage area.

(b) *Other soils:* (Types C and D and some Type B not meeting the criterion in 2a above)

- Dispersion area must have 6.5 feet of width for every 1-foot width of impervious area draining to it. A minimum distance of 100 feet is necessary.

(c) *Other criteria applicable to all soil types:*

- Depth to the average annual maximum groundwater elevation should be at least 3 feet.
- Channelized flow must be re-dispersed to produce the longest possible flow path.
- Flows must be evenly dispersed across the dispersion area.
- Flows must be dispersed using rock pads and dispersion techniques as specified in BMP T5.30 of the 2005 SMMWW.
- Approved energy dissipation techniques may be used.
- Limited to on-site (associated with the road) flows.
- Length of dispersion area should be equivalent to length of the road.
- Average longitudinal and lateral slopes of the dispersion area should be ≤ 8 percent.

(3) Engineered dispersion of stormwater runoff into an area with engineered soils

Full dispersion credit (i.e., no other treatment or flow control required) is given to projects that meet the following criteria:

- Stormwater can be dispersed via sheet flow or via collection and re-dispersion in accordance with the techniques specified in BMP T5.30 of the 2005 SMMWW.

- Depth to the average annual maximum groundwater elevation should be at least 3 feet.
- Type C and D soils must be compost-amended following guidelines in Section 6.2: Amending Construction Site Soils. The guidance document *Guidelines and Resources for Implementing Soil Depth & Quality BMP T5.13 in WDOE Western Washington Stormwater Manual*, 2003 (revised 2005) can be used, or an approved equivalent soil quality and depth specification approved by Ecology.
    - Dispersion area must meet the 6.5 to 1 ratio for full dispersion credit.
- Type A and B soils that meet the 4 inches per hour initial saturated infiltration rate minimum (See Section 7.2.4 a above) must be compost-amended in accordance with guidelines in Section 6.2: Amending Construction Site Soils. Compost may be incorporated into the soil in accordance with the guidance document cited above, or can be placed on top the native soil.
    - 20 feet of impervious flow path needs 10 feet of dispersion area width.
    - Each additional foot of impervious flow path needs 0.25 feet of dispersion area width.
- Average longitudinal (parallel to road) slope of dispersion area should be ≤ 15 percent.
- Average lateral slope of dispersion area should be ≤ 15 percent.
- The dispersion area should be planted with native trees and shrubs.

(4) Other characteristics for dispersal areas

- Dispersal areas inside the urban growth area must be protected through legal agreements (easements, conservation tracts, public parks).
- If outside urban growth areas, legal agreements should be reached with property owners of dispersal areas subject to stormwater that has been collected and is being re-dispersed.
- An agreement with the property owner is advised for uncollected, natural dispersion via sheet flow that is a continuation of past practice. If not a continuation of past practice, an agreement should be reached with the property owner.

7.3 Vegetated Roofs

7.3.1 Option 1 Design Criteria

- 3 to 8 inches of soil/growing media

Runoff Model Representation

- till landscaped area

7.3.2 Option 2 Design Criteria

- > 8 inches of soil/media

Runoff Model Representation

- till pasture

7.3.3 Other Necessary Design Criteria

- Soil or growth media that has a high field capacity, and a saturated hydraulic conductivity that is ≥ 1 inch/hour (i.e., equivalent to a sandy loam or soil with a higher hydraulic conductivity).
- Drainage layer that allows free drainage under the soil/media.
- Vegetative cover that is both drought and wet tolerant.
- Waterproof membrane between the drain layer and the structural roof support.
- Maximum slope of 20 percent.

7.4 Rainwater Harvesting

7.4.1 Design Criteria

- 100 percent reuse of the annual average runoff volume (use continuous runoff model to get annual average for drainage area).
- System designs involving interior uses must have a monthly water balance that demonstrates adequate capacity for each month and reuse of all stored water annually.

Runoff Model Representation:

- Do not enter drainage area into the runoff model.

7.4.2 Other Criteria

- Restrict use to 4 homes/acre housing and lower densities when the captured water is solely for outdoor use.

7.5 Reverse Slope Sidewalks

Reverse slope sidewalks are sloped to drain away from the road and onto adjacent vegetated areas.

7.5.1 Design Criteria:

- ≥ 10 feet of vegetated surface downslope that is not directly connected into the storm drainage system.
- Vegetated area receiving flow from sidewalk must be undisturbed native soil or meet guidelines in Section 6.2: Amending Construction Site Soils.

7.5.2 Runoff Model Representation:

- Enter sidewalk area as landscaped area.

7.6 Minimal Excavation Foundations

Low impact foundations are defined as those techniques that do not disturb, or minimally disturb, the natural soil profile within the footprint of the structure. This preserves most of the hydrologic properties of the native soil. Pin foundations are an example of a minimal excavation foundation.

7.6.1 Runoff Model Representation

- Where residential roof runoff is dispersed on the up gradient side of a structure in accordance with the design criteria and guidelines in BMP T5.10 of the 2005 SMMWW, the tributary roof area may be modeled as pasture on the native soil.
- Where "step forming" is used on a slope, the square footage of roof that can be modeled as pasture must be reduced to account for lost soils. In "step forming," the building area is terraced in cuts of limited depth. This results in a series of level plateaus on which to erect the form boards. The following equation (suggested by Rick Gagliano of Pin Foundations, Inc.) can be used to reduce the roof area that can be modeled as pasture.

$$A_1 - \frac{dC(.5)}{dP} X A_1 = A_2$$

A_1 = roof area draining to up gradient side of structure
dC = depth of cuts into the soil profile
dP = permeable depth of soil (The A horizon plus an additional few inches of the B horizon where roots permeate into ample pore space of soil)
A_2 = roof area that can be modeled as pasture on the native soil

- If roof runoff is dispersed down gradient of the structure in accordance with the design criteria and guidelines in BMP T5.10 of the 2005 SMMWW AND there is at least 50 feet of vegetated flow path through native material or lawn/ landscape area that meets the guidelines in Section 6.2: Amending Construction Site Soils, the tributary roof areas may be modeled as landscaped area.

7.6.2 Limitations

- To minimize soil compaction, heavy equipment cannot be used within or immediately surrounding the building. Terracing of the foundation area may be accomplished by tracked, blading equipment not exceeding 650 psf.

7.7 Bioretention Areas (Rain Gardens)

The design criteria provided below outlines basic guidance on bioretention design specifications, procedures for determining infiltration rates, and flow control guidance. For details on design specifications see Section 6.1: Bioretention Areas.

7.7.1 Design Criteria

Soils

- The soils surrounding bioretention facilities are a principle design element for determining infiltration capacity, sizing, and rain garden type. The planting soil mix placed in the cell or swale is a highly permeable soil mixed thoroughly with compost amendment and a surface mulch layer.
- Soil depth should be a minimum of 18 inches to provide acceptable minimum pollutant attenuation and good growing conditions for selected plants.
- The texture for the soil component of the bioretention soil mix should be a loamy sand (USDA Soil Textural Classification). Clay content for the final soil mix should be less than 5 percent. The final soil mix (including compost and soil) should have a minimum long-term hydraulic conductivity of 1.0 inch/hour

per ASTM Designation D 2434 (Standard Test Method for Permeability of Granular Soils) at 80 percent compaction per ASTM Designation D 1557.

- The final soil mixture should have a minimum organic content of approximately 10 percent by dry weight.
- The pH for the soil mix should be between 5.5 and 7.0.

Mulch layer

- Bioretention areas can be designed with or without a mulch layer.

Compost

- Material must be in compliance with WAC chapter 173-350 Section 220 and meet Type 1, 2, 3 or 4 feedstock.
- pH between 5.5 and 7.0.
- Carbon nitrogen ratio between 20:1 and 35:1 (35:1 CN ratio recommended for native plants).
- Organic matter content should be between 40 and 50 percent.

Installation

- Minimize compaction of the base and sidewalls of the bioretention area. Excavation should not be allowed during wet or saturated conditions. Excavation should be performed by machinery operating adjacent to the bioretention facility and no heavy equipment with narrow tracks, narrow tires or large lugged, high pressure tires should be allowed on the bottom of the bioretention facility.
- On-site soil mixing or placement should not be performed if soil is saturated. The bioretention soil mixture should be placed and graded by excavators and/or backhoes operating adjacent to the bioretention facility.

Plant materials

- Plants should be tolerant of ponding fluctuations and saturated soil conditions for the length of time anticipated by the facility design and drought during the summer months.
- In general, the predominant plant material utilized in bioretention areas are facultative species adapted to stresses associated with wet and dry conditions.

Maximum ponding depth

- A maximum ponding depth of 12 inches is recommended.
- A maximum surface pool drawdown time of 24 hours is recommended.
- Ponding depth and system drawdown should be specified so that soils dry out periodically in order to:
    - o Restore hydraulic capacity to receive flows from subsequent storms.
    - o Maintain infiltration rates.
    - o Maintain adequate soil oxygen levels for healthy soil biota and vegetation.
    - o Provide proper soil conditions for biodegradation and retention of pollutants.

7.7.2 Limitations

- A minimum of 3 feet of clearance is necessary between the lowest elevation of the bioretention soil, or any underlying gravel layer, and the seasonal high groundwater elevation or other impermeable layer, if the area tributary to the rain garden meets or exceeds any of the following limitations:
  - 5,000 square feet of pollution-generating impervious surface; or
  - 10,000 square feet of impervious area; or
  - ¾ acre of lawn and landscape.
- If the tributary area to an individual rain garden does not exceed the areal limitations above, a minimum of 1 foot of clearance is adequate between the lowest elevation of the bioretention soil (or any underlying gravel layer) and the seasonal high groundwater elevation or other impermeable layer.

7.7.3 Runoff Model Representation

Pothole Design (Bioretention Cells)

The rain garden is represented as a pond with a steady-state infiltration rate. Proper infiltration rate selection is described below. The pond volume is a combination of the above ground volume available for water storage and the volume available for storage within the planting soil mix. The latter volume is determined by multiplying the volume occupied by the planting soil mix by the soil's percent porosity. Use 40 percent porosity for bioretention planting mix soils recommended in Section 6.1.2.3: Bioretention components. That volume is presumed to be added directly below the surface soil profile of the rain garden. The theoretical pond dimensions are represented in the Pond Information/Design screen. The Effective Depth is the distance from the bottom of the theoretical pond to the height of the overflow. This depth is less than the actual depth because of the volume occupied by the soil. Approximate side slopes can be individually entered. On the Pond Information/Design screen, a button asks: "Use Wetted Surface Area?" Pushing that button is an affirmative response. Do not push the button if the rain garden has sidewalls steeper than 2 horizontal to 1 vertical.

Rain gardens with underlying perforated drain pipes that discharge to the surface can also be modeled as ponds with steady-state infiltration rates. However, the only volume available for storage (and modeled as storage as explained herein) is the void space within the imported material (usually sand or gravel) below the invert of the drain pipe.

Linear design: (bioretention swale or slopes)

Swales

Where a swale design has a roadside slope and a back slope between which water can pond due to an elevated, overflow/drainage pipe at the lower end of the swale, the swale may be modeled as a pond with a steady-state infiltration rate. This method does not apply to swales that are underlain by a drainage pipe.

If the long-term infiltration rate through the imported bioretention soil is lower than the infiltration rate of the underlying soil, the surface dimensions and slopes of the swale should be entered into the WWHM as the pond dimensions and slopes. The effective depth is the distance from the soil surface at the bottom of the swale to the invert of the overflow/drainage pipe. If the infiltration rate through the underlying soil is lower than the estimated long-term infiltration rate through the imported bioretention soil, the pond dimensions entered into the WWHM should be adjusted to account for the storage volume in the void space of the bioretention soil. Use 40 percent porosity for bioretention planting mix soils recommended in Section 6.1.2.3: Bioretention components. For instance, if the soil is 40 percent voids, and the depth of the imported soils is 2 feet throughout the swale, the depth of the pond is increased by 0.8 feet. If the depth of imported soils varies within the side slopes of the swale, the theoretical side slopes of the pond can be adjusted.

This procedure to estimate storage space should only be used on bioretention swales with a 1 percent slope or less. Swales with higher slopes should more accurately compute the storage volume in the swale below the drainage pipe invert.

Slopes

Where a bioretention design involves only a sloped surface such as the slope below the shoulder of an elevated road, the design can also be modeled as a pond with a steady state infiltration rate. This procedure only applies in instances where the infiltration rate through the underlying soil is less than the estimated long-term infiltration rate of the bioretention planting soil mix. In this case, the length of the bioretention slope should correspond to the maximum wetted cross-sectional area of the theoretical pond. The effective depth of the theoretical pond is the void depth of the bioretention soil as estimated by multiplying the measured porosity times the depth of the bioretention soils. Use 40 percent porosity for bioretention planting mix soils recommended in Section 6.1.2.3: Bioretention components.

7.7.4 Infiltration Rate Determinations

The assumed infiltration rate for the pond must be the lower of the estimated long-term rate of the planting soil mix or the initial (a.k.a. short-term or measured) infiltration rate of the underlying soil profile. Using one of the procedures explained below, the initial infiltration rates of the two soils must be determined. Then after applying an appropriate correction factor to the planting soil mix placed in the rain garden, the designer can compare and determine the lower of the long-term infiltration rate of the planting soil mix and the initial infiltration rate of the underlying native soil. The underlying native soil does not need a correction factor because the overlying planting soil mix protects it. Below are explanations for how to determine infiltration rates for the planting soil mix and underlying soils, and how to use them with the WWHM.

7.7.4.1 Planting soil mix for the rain garden

1. Method for determining the infiltration rate for the planting soil mix in a rain garden with a tributary area of or exceeding any of the following limitations: 5,000 square feet of pollution-generating impervious surface; or 10,000 square feet of impervious surface; or ¾ acre of lawn and landscape:
   - Use ASTM D 2434 Standard Test Method for Permeability of granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
   - Use 4 as the infiltration reduction correction factor.
   - Compare this rate to the infiltration rate of the underlying soil (as determined using one of the methods below). If the long-term infiltration

rate of the imported soil is lower, enter that infiltration rate and the correction factor into the corresponding boxes on the pond information/design screen of the WWHM.

2. Method for determining the infiltration rate for the planting soil mix in a rain garden with a tributary area less than 5,000 square feet of pollution-generating impervious surface; and less than 10,000 square feet of impervious surface; and less than ¾ acre of lawn and landscape:
   - Use ASTM D 2434 Standard Test Method for Permeability of granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
   - Use 2 as the infiltration reduction correction factor.
   - Compare this rate to the infiltration rate of the underlying soil (as determined using one of the methods below). If the long-term infiltration rate of the imported soil is lower, enter that infiltration rate and the correction factor into the corresponding boxes on the pond information/design screen of the WWHM.

7.7.4.2 Underlying soil

- Method 1: Use Table 3.7 of the 2005 SMMWW to determine the short-term infiltration rate of the underlying soil. Soils not listed in the table cannot use this approach. Compare this short-term rate to the long-term rate determined above for the bioretention-imported soil. If the short-term rate for the underlying soil is lower, enter it into the measured infiltration rate box on the pond information/design screen in the WWHM. Enter 1 as the infiltration reduction factor.
- Method 2: Determine the D_{10} size of the underlying soil. Use the "upperbound line" in Figure 4-17 of the WSDOT Highway Runoff Manual to determine the corresponding infiltration rate. If this infiltration rate is lower than the long-term infiltration rate determined for the bioretention planting soil mix, enter the rate for the underlying soil into the measured infiltration rate box on the pond/information design screen. Enter 1 as the infiltration reduction factor.
- Method 3: Measure the in-situ infiltration rate of the underlying soil using procedures (Pilot Infiltration Test) identified in Appendix III-D (formerly V-B) of the 2005 SMMWW. If this rate is lower than the long-term infiltration rate determined for the imported bioretention soil, enter the underlying soil infiltration rate into the corresponding box on the pond information/design screen of the WWHM. Enter 1 as the infiltration reduction factor.

7.7.5 WWHM Routing and Runoff File Evaluation

In WWHM2 (the most recent WWHM iteration), all infiltrating facilities must have an overflow riser to model overflows that occur should the available storage be exceeded. In the Riser/Weir screen for the Riser head, enter a value slightly smaller than the effective depth of the pond (e.g., 0.1 foot below the Effective Depth), and for the Riser diameter enter a large number (e.g., 10,000 inches) to ensure that there is ample capacity for overflows.

Within the model, route the runoff into the pond by grabbing the pond icon and placing it below the tributary "basin" area. Be sure to include the surface area of the bioretention area in the tributary "basin" area. Run the model to produce the effluent runoff file from the theoretical pond. For projects subject to the flow control standard, compare the flow duration graph of that runoff file to the target pre-developed runoff file for compliance with the flow duration standard. If the standard is not achieved a downstream retention or detention facility must be sized (using the WWHM standard procedures) and located in the field. A conveyance system should be designed to route all overflows from the bioretention areas to centralized treatment facilities, and to flow control facilities if flow control applies to the project.

7.7.6 Modeling of Multiple Rain Gardens

Where multiple rain gardens are scattered throughout a development, it may be possible to represent those as one rain garden (a "pond" in the WWHM) serving the cumulative area tributary to those rain gardens. For this to be a reasonable representation, the design of each rain garden should be similar (e.g., same depth of soil, same depth of surface ponded water, and approximately the same ratio of impervious area to rain garden volume).

7.7.7 Other Rain Garden Designs

Guidance for modeling other bioretention designs is not yet available. However, where compost-amended soils are used along roadsides the guidance in Section 7.2: Dispersion can be applied.

7.8 WWHM Instructions for Estimating Runoff Losses in Road Base Material Volumes that are Below Surrounding Grade

Pre-requisite

Before using this guidance to estimate infiltration losses, the designer should have sufficient information to know whether adequate depth to a seasonal high groundwater table, or other infiltration barrier (such as bedrock) is available. The minimum depth necessary is 3 feet as measured from the bottom of the base materials.

7.8.1 Instructions for Roads on Zero- to 2-percent Grade

For road projects whose base materials extend below the surrounding grade, a portion of the below grade volume of base materials may be modeled in the WWHM as a pond with a set infiltration rate.

First, place a "basin" icon in the "Schematic" grid on the left side of the "Scenario Editor" screen. Left clicking on the basin icon will create a "basin information" screen on the right in which you enter the appropriate pre-developed and post-developed descriptions of your project site (or threshold discharge area of the project site). By placing a pond icon below the basin icon in the Schematic grid, we are routing the runoff from the road and any other tributary area into the below grade volume that is represented by the pond.

The dimensions of the infiltration basin/pond to be entered in the Pond Information/Design screen are: the length of the base materials that are below grade (parallel to the road); the width of the below grade material volume; and the

Effective Depth. Note that the storage/void volume of the below grade base has to be estimated to account for the percent porosity of the gravel. This can be done by multiplying the below grade depth of base materials by the fractional porosity (e.g., a project with a gravel base of 32 percent porosity would multiply the below grade base material depth by 0.32). This is the Effective Depth. If the below grade base course has perforated drainage pipes elevated above the bottom of the base course, but below the elevation of the surrounding ground surface, the Effective Depth is the distance from the invert of the lowest pipe to the bottom of the base course multiplied by the fractional porosity.

Also in WWHM2, all infiltrating facilities must have an overflow riser to model overflows that occur should the available storage be exceeded. In the Riser/Weir screen, for the Riser head enter a value slightly smaller than the effective depth of the base materials (e.g., 0.1 foot below the Effective Depth), and for the Riser diameter enter a large value (e.g., 10,000 inches) to ensure that there is ample capacity should overflows from the trench occur.

On the Pond Information/Design screen, there is a button that asks, "Use Wetted Surface Area?" Pushing that button is an affirmative response. Do not push the button.

Using the procedures explained in Volume III, Chapter 3 and Appendix III-D of the 2005 SMMWW, or in Section 4-5.2 of the 2004 WSDOT Highway Runoff Manual, estimate the long-term infiltration rate of the native soils beneath the base materials. If using Method 1 from Chapter III of the 2005 SMMWW, enter the appropriate "short-term infiltration rate" from Table 3.7 into the "measured infiltration rate" box on the "Pond Information Design" screen of WWHM. Enter the correction factor from that table as the "Infiltration Reduction Factor." If using Method 2, enter the appropriate long-term infiltration rate from Table 3.8 into the "measured infiltration rate" box. Enter 1 as the correction factor. Note that Table 3.8 is restricted to the soil types in the table. For soils with a D_{10} size smaller than .05 mm, use the "lowerbound" values from Figure 4-17 on page 4-56, Chapter 4 of the 2004 WSDOT Highway Runoff Manual. If using Method 3, enter the measured in-situ infiltration rate as the "Measured Infiltration Rate" in the Pond Information/Design Screen. Also enter the appropriate cumulative correction factor determined from Table 3.9 as the "Infiltration Reduction Factor." Wherever practicable, Ecology recommends using Method 3, in-situ infiltration measurements (Pilot Infiltration Test) in accordance with Appendix III-D of the 2005 SMMWW.

Run the model to produce the overflow runoff file from the base materials infiltration basin. Compare the flow duration graph of that runoff file to the target pre-developed runoff file for compliance with the flow duration standard. If the standard is not achieved a downstream retention or detention facility must be sized (using the WWHM standard procedures) and located in the field. The road base materials should be designed to direct any water that does not infiltrate into a conveyance system that leads to the retention or detention facility.

7.8.2 Instructions for Roads on Grades Above 2 Percent

Road base material volumes that are below the surrounding grade and on a slope can be modeled as a pond with an infiltration rate and a nominal depth. Represent the below grade volume as a pond. Grab the pond icon and place it below the "basin" icon so that the computer model routes all of the runoff into the infiltration basin/pond.

The dimensions of the infiltration basin/pond to be entered in the Pond Information/Design screen are: the length (parallel to and beneath the road) of the base materials that are below grade; the width of the below grade base materials; and an Effective Depth of 1 inch. In WWHM2, all infiltrating facilities must have an overflow riser to model overflows should the available storage be exceeded. In the Riser/Weir screen, enter 0.04 foot (½ inch) for the Riser head and a large Riser diameter (e.g., 1000 inches) to ensure that there is no head build up.

Note: If a drainage pipe is embedded and elevated in the below grade base materials, the pipe should only have perforations on the lower half (below the spring line) or near the invert. Pipe volume and trench volume above the pipe invert cannot be assumed as available storage space.

Estimate the infiltration rate of the native soils beneath the base materials. See Section 7.8.1: Roads on zero to 2 percent grade for estimating options and how to enter infiltration rates and infiltration reduction factors into the "Pond Information/ Design" Screen of WWHM. Enter the appropriate information for the theoretical pond of ½-inch maximum depth.

On the Pond Information/Design screen, there is a button that asks, "Use Wetted Surface Area?" Pushing that button is an affirmative response. Do not push the button.

Run the model to produce the effluent runoff file from the base materials. Compare the flow duration graph of that runoff file to the target pre-developed runoff file for compliance with the flow duration standard. If the standard is not achieved a downstream retention or detention facility must be sized (using the WWHM standard procedures) and located in the field. The road base materials should be designed to direct any water that does not infiltrate into a conveyance system that leads to the retention or detention facility.

7.8.3 Instructions for Roads on a Slope With Internal Dams Within the Base Materials that are Below Grade

In this option, a series of infiltration basins are created by placing relatively impermeable barriers across the below grade base materials at intervals. The barriers inhibit the free flow of water down the grade of the base materials. The barriers must not extend to the elevation of the surrounding ground. Provide a space sufficient to pass water from upgradient to lower gradient basins without causing flows to surface out the sides of the base materials that are above grade.

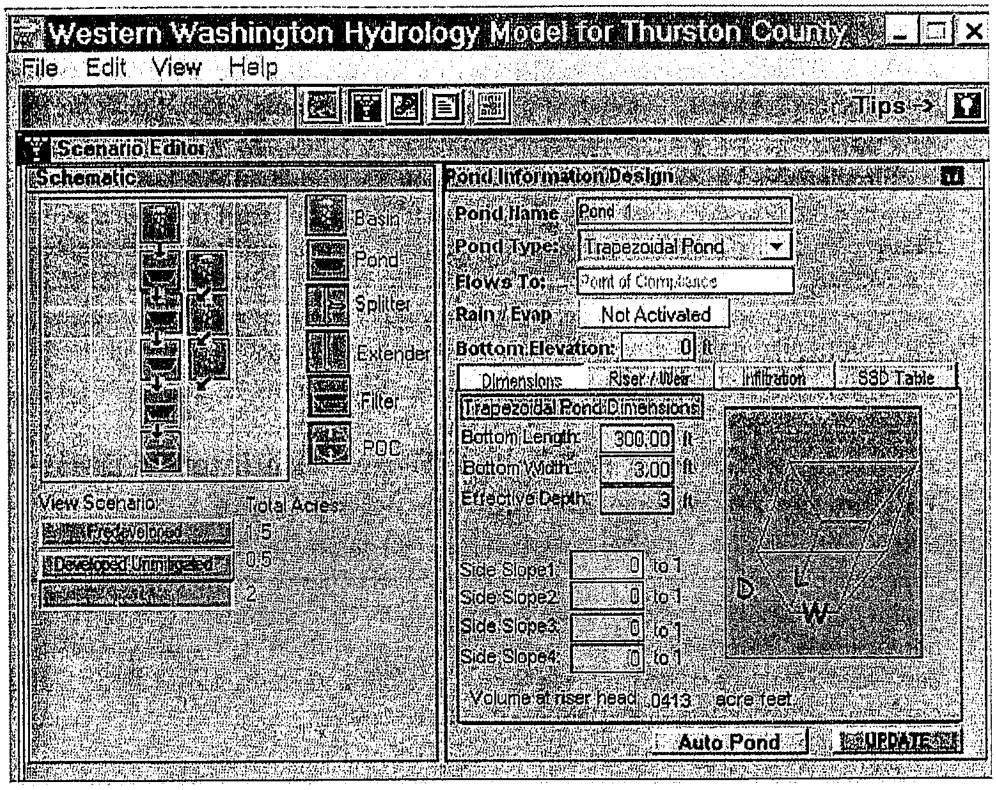
Each stretch of trench (cell) that is separated by barriers can be modeled as an infiltration basin. This is done by placing pond icons in a series in the WWHM. For each cell, determine the average depth of water within the cell (Average Cell Depth) at which the barrier at the lower end will be overtopped.

Specify the dimensions of each cell of the below grade base materials in WWHM on the screen which asks for pond dimensions. The dimensions of the infiltration cell entered in the Pond Information/Design screen are: the length of the cell (parallel to the road); the width; and the Effective Depth (in this case, it is okay to use the total depth of the base materials that are below grade).

Also in WWHM2, all infiltrating facilities must have an overflow riser to model overflows should the available storage be exceeded. For each trench cell, the available storage is the void space within the Average Cell Depth. The storage/void volume of the trench cell has to be estimated to account for the percent porosity of the base materials. For instance, if the base materials have a porosity of 32 percent, the void volume can be represented by reducing the Average Cell Depth by 68 percent (1 to 32 percent). This depth is entered in the Riser/Weir screen as the Riser head. The gross adjustment works because WWHM2 (as of March 2004) does not adjust infiltration rate as a function of water head. If the model is amended so that the infiltration rate becomes a function of water head, this gross adjustment will introduce error and therefore other adjustments should be made. For the riser diameter in the Riser/Weir screen, enter a large number (e.g., 10,000 inches) to ensure that there is ample capacity if overflows from the below-grade trench occur.

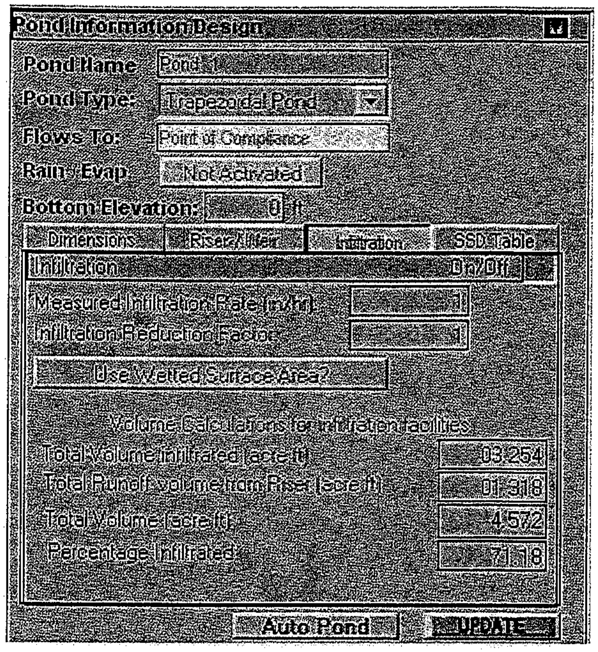
Each cell should have its own tributary drainage area that includes the road above it, any project site pervious areas whose runoff drains onto and through the road, and any off-site areas. Each drainage area is represented with a "basin" icon.

Up to four pond icons can be placed in a series to represent the below grade trench of base materials. The computer graphic representation of this appears as follows:



It is possible to represent a series of cells as one infiltration basin (using a single pond icon) if the cells all have similar length and width dimensions, slope, and Average Cell Depth. A single "basin" icon is also used to represent all of the drainage area into the series of cells.

On the Pond Information/Design screen (see screen below), there is a button that asks, "Use Wetted Surface Area?" Pushing that button is an affirmative response. Do not push the button if the below grade base material trench has sidewalls steeper than 2 horizontal to 1 vertical.



Using the procedures explained above for roads on zero grade, estimate the infiltration rate of the native soils beneath the trench. Also as explained above, enter the appropriate values into the "Measured Infiltration Rate" and "Infiltration Reduction Factor" boxes of the "Pond Information/Design" screen.

Run the model to produce the effluent runoff file from the below grade trench of base materials. Compare the flow duration graph of that runoff file to the target pre-developed runoff file for compliance with the flow duration standard. If the standard is not achieved a downstream retention or detention facility must be sized (using the WWHM standard procedures) and located in the field. The road base materials should be designed to direct any water that does not infiltrate into a conveyance system that leads to the retention or detention facility.

8 Hydrologic Analysis

IN THIS CHAPTER...

- *Emerging techniques for modeling LID*

Several methods of hydrologic analysis have been developed for modeling low impact development (LID) designs. Single event models have been most commonly used and a national method based on the Soil Conservation Service TR-55 model is available through the U.S. Environmental Protection Agency (EPA publication 841-B-00-02).

Single event methods, however, have limitations for modeling western Washington stormwater facilities. For example, a single event method does not account for the effects of storms that occur just before or after a single storm event and the associated antecedent soil moisture conditions.

The Washington Department of Ecology (Ecology) recommends that local jurisdictions in western Washington adopt the Western Washington Hydrologic Model (WWHM), an HSPF (Hydrologic Simulation Program-Fortran)-based model. Ecology recommends WWHM for several reasons, including:

- WWHM uses long-term and local precipitation data that accounts for various rainfall regimes in western Washington.
- The modeling methodology better accounts for previous storm events and antecedent soil moisture conditions.
- The various land categories describing hydrologic factors that influence runoff characteristics are calibrated using data collected by the U.S. Geological Service (USGS) in western Washington watersheds.

While WWHM provides advantages for designing stormwater facilities in western Washington, there are challenges for applying the model to low impact development designs. LID utilizes multiple, small-scale stormwater controls that are distributed yet often connected throughout the development. Flows are directed to these facilities from small contributing areas and stormwater that is not infiltrated, evaporated or transpired in one facility is directed to the next. This presents two challenges when using WWHM in this design setting:

- WWHM has limited routing capability, and while the model has been expanded to allow routing through multiple facilities, the procedure remains time and computing intensive for the large number of facilities in LID projects (AHBL, 2004).
- Pervious land category values (PERLNDs) for WWHM are based on local USGS studies. Pervious surfaces and soil treatments in a low impact development include compost amended soil, bioretention areas with engineered soil mixes, and pervious pavement with aggregate storage. The LID pervious surface treatments, or land categories, will likely behave differently than the calibrated PERLNDs in the WWHM. Pilot projects and associated monitoring are needed to provide necessary data to help further calibrate the WWHM to these new strategies.

8.1 Emerging Modeling Techniques

8.1.1 Micro-Basin Characterization

AHBL Engineers in Tacoma developed a micro-basin characterization technique to compensate for the routing limitations of the WWHM:

- The project is divided into small basins according to topography, lot, and street layout and LID stormwater facility configuration (see Figure 8.1 for a conceptual representation of the basin delineation).
- The contributing area is based on the bioretention cell or segment of bioretention swale and the area that contributes surface flows to that cell or swale.
- Areas are derived from design plans for roof areas, driveways, landscaping, and undisturbed areas for each basin.
- Storm flows from the basin are then routed through the bioretention cell or portion of the bioretention swale.
- An equivalent basin is generated that has characteristics that match the outflow from the bioretention cell or segment of swale.
- After all individual basins are defined, they are combined and routed to the next facility or used for the final development runoff.
(AHBL, 2004)

Contributing Area Delineation for Hydrologic Modeling

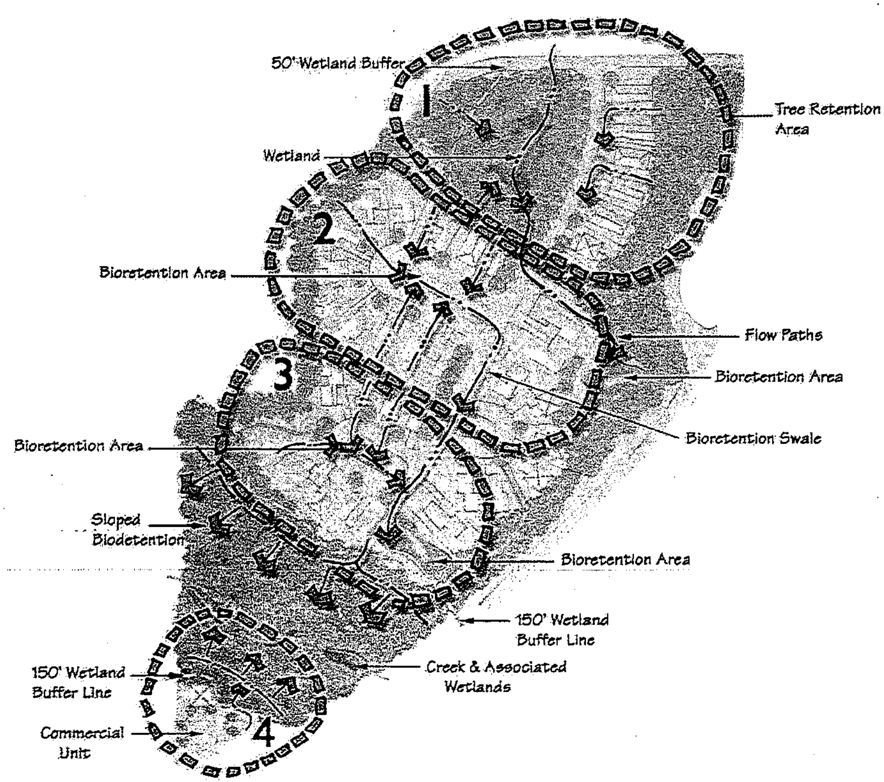


Figure 8.1 Basin delineation.

Graphic by AHBL Engineering

8.1.2 WWHM and LID Flow Control Credits

See Chapter 7: Washington Department of Ecology Low Impact Development Design and Flow Modeling Guidance for flow control credits when using bioretention, green roofs, rooftop rainwater harvesting, permeable paving, minimal excavation foundations, and dispersion techniques.

8.1.3 An Approach for Modeling Bioretention Swales and Compost Amended Soils

Herrera Environmental Consultants performed hydrologic modeling to evaluate the expected performance of a Natural Drainage System (NDS) for the High Point Revitalization Project in Seattle. The primary objectives of the hydrologic modeling were to evaluate compliance with overall stormwater performance goals for the site, cost effectiveness, and design optimization for the NDS.

Key elements of the proposed NDS include bioretention and conveyance swales that are distributed throughout the site within the public rights-of-way, disconnection of rooftop runoff from the storm drain system, and extensive use of compost amended soils.

Existing models are not ideally suited for examining the microscopic surface and subsurface dynamics of bioretention swales and their complex interaction with other stormwater management practices (e.g., rooftop dispersion and compost amended soil). Accordingly, Herrera developed new modeling techniques to more accurately assess the detailed performance of the bioretention swales at the city block-scale, as well as the cumulative performance of all elements of the NDS strategy for the entire High Point site.

The bioretention swales for High Point are complex in design, with multiple distinct layers governing their flow control capacity. These layers consist of a grass-lined or vegetated swale surface, a 6-foot thick engineered soil layer, and a 6-foot thick gravel under-drain layer. The swale is designed to retain stormwater at the surface long enough to allow infiltration into the underlying engineered soil layer. The engineered soil provides the primary mechanism for flow control. Stormwater is retained for longer periods of time and is exfiltrated through the sides of the swale to surrounding native soils. Moisture that does not exfiltrate within the engineered soil layer drains to the underlying gravel layer, which allows for additional exfiltration through the sides and bottom of the swale.

The bioretention swales were modeled in HSPF as a series of interconnected stage-storage-discharge relationships, or functional tables (FTABLEs). One FTABLE was used to represent each distinct layer of the swale. For the grass-lined or vegetated surface swale, FTABLE development was based on Manning's equation for open channels. The FTABLE for the engineered soil layer was of critical importance for predicting the overall performance of the bioretention swales, since this layer provides the primary flow control mechanism for the swales. This FTABLE was developed based on detailed modeling performed using MODRET software, which is a groundwater model capable of predicting dynamic surface water and groundwater interactions. The FTABLE for the under-drain layer was based on Darcy's Law for saturated flow through gravel. The FTABLEs for each layer were connected within HSPF, allowing for exfiltration to the native soils as well as one-way flow between layers (e.g., from the surface swale to the engineered soil layer, or from the engineered soil to the under-drain layer).

For the overall site-scale modeling, compost amended soils were modeled in HSPF as PERLNDs with lateral inflow from disconnected rooftop downspouts. Model parameters for these PERLNDs were modified from the USGS regional calibration parameters for till soils with grass cover in order to represent the enhanced infiltration offered by amended soils (Dinicola, 1990). The parameter adjustments were based on an HSPF calibration study by Kurtz (1996), which used data obtained from experimental plots at the University of Washington's Center for Urban Horticulture.

Runoff from rooftops was modeled as lateral inflow to lawns, or compost amended soil, down gradient from the downspouts. Lateral inflow is analogous to additional rainfall input to these receiving areas. For purposes of reflecting reasonable hydraulic loading rates, the areas receiving rooftop runoff were estimated using the following approach:

- Each building structure was assumed to have four downspouts contributing to the adjacent pervious area.
- Downspout discharge was assumed to spread at a 45 degree angle and sheet flow a distance of 10 feet onto the adjacent pervious area.

This modeling approach was successful for meeting the objectives of the study. Long-term monitoring of the site is scheduled to begin Fall 2004. Results from the monitoring study will be used to verify the modeling approach.

8.1.4 CH2M HILL LIFE™ Model

CH2M HILL developed the Low Impact Feasibility Evaluation (LIFE™) model specifically for evaluating the performance of various LID techniques. The LIFE™ model provides a continuous simulation of the runoff and infiltration from new or redeveloped areas, or from a watershed or sub-catchment with multiple land use categories utilizing the following inputs:

- Continuous rainfall data (typically in time increments of 1 hour or less) and evapotranspiration data (typically daily time increments) evaluated for time periods of one year or more.
- Site design parameters and land cover characteristics for each land category being modeled (e.g., road width, rooftop coverage, surface parking, etc.).
- Information on LID techniques that are applied for each land use type including:
    - Extent of source control application (e.g., percent of road and building lots with specific source controls).
    - Source control design parameters (e.g., area and depth of infiltration facilities, soil depth for green roofs, volume of rainwater harvesting cisterns, etc.).
- Soils information including:
    - Surface parameters (e.g., maximum water content, rooting depth of vegetation).
    - Subsurface parameters (e.g., saturated hydraulic conductivity).

The model provides total runoff volume, flow duration curves, and flow hydrographs as outputs to assess the performance of LID designs (CH2M HILL, 2004).

The LIFE™ model has not had extensive calibration. Pilot projects and associated monitoring will provide necessary data to help further calibrate the model to specific LID practices and expected overall performance of projects using multiple LID techniques.

Appendix 1

Street Tree List

The following list provides information on the growth patterns and favorable site characteristics for trees that are appropriate in the street landscape. Bioretention cells and swales located along streets may have specific soil and moisture conditions that differ from conventional roadside planting areas. Trees in this list may be applicable in bioretention areas depending on the physical setting and project objectives. See Appendix 3 for trees specifically recommended in bioretention cells or swales.

Local jurisdictions often have specific guidelines for the types and location of trees planted along public streets or rights-of-way. The extent and growth pattern of the root structure must be considered when trees are planted in bioretention areas or other stormwater facilities with under-drain structures or near paved areas such as driveways, sidewalks or streets. The city of Seattle, for example, has the following requirements for tree planting location:

- 3½ feet back from the face of the curb.
- 5 feet from underground utility lines.
- 10 to 15 feet from power poles.
- 7½ to 10 feet from driveways.
- 20 feet from street lights or other existing trees.
- 30 feet from street intersections.
- Planting strips for trees should be at least 5 feet wide.

Trees included in the "small" tree section of this list typically remain at or below a 30-foot mature height, which is compatible (unless indicated otherwise) with clearances for most overhead utility/electrical lines. Some jurisdictions may not recommend planting street trees that are fruit bearing or are otherwise "messy." Contact local authorities to determine if there are guidelines or restrictions to consider when making tree selections in your area.

Minimum ranges for planting strip widths are included and are compiled from various local and regional jurisdiction recommendations. Generally, larger planting widths are recommended for optimal tree health and longevity. Under certain circumstances, the use of root barriers or root guards may assist in preventing or delaying damage to adjacent paved surfaces. Consult a certified arborist for specifications and information on root barriers and installation.

Note on conifers: Jurisdictions often recommend very large planting areas for conifers due to potential visibility or safety issues associated with lower limbs. If properly trimmed and maintained, however, conifers can be incorporated safely into the urban streetscape and provide excellent year-round interception of precipitation.

💧 Indicates a tree that does well in wet areas | * Denotes native species

Small Trees (under 30 feet in height)

Space evenly every 20 to 30 feet

Species/ Common Name	Exposure	MatureHt./ Spread	Planting Strip Width	Comments
Acer campestre Hedge maple	Sun/partial shade	To 30 feet/ To 30 ft. spread	4-5 feet	Deciduous; prefers moist, rich soils; slow growing tree tolerant of air pollution and soil compaction; yellow fall color; cultivars available including Queen Elizabeth maple ('Evelyn') with dark green, glossy foliage
*Acer circinatum** Vine maple	Sun/partial shade	20-25 feet/ 10 ft. spread	8 feet	Deciduous; prefers moist, well-drained soils; tolerates seasonal saturation and varying soil types; drought tolerant once established; bushy shrub or small tree; most often multi-trunked and does well in small groups; white flowers April-June; orange and red fall color
Acer ginnala Amur maple	Sun/partial shade	To 20 feet/ 20 ft. spread	4 feet	Deciduous; prefers moist, well-drained soils, but is tolerant of drought; is often multi-trunked, but can be pruned to a single stem; rounded form; fragrant, yellowish-white flowers in spring; cultivars are available such as 'Flame' and 'Embers' with differing fall colors
Acer griseum Paperbark maple	Sun/partial shade	15-25 feet/ 15-25 ft. spread	4 feet	Deciduous; prefers moist, well-drained soils, but is moderately drought tolerant; bronze peeling bark provides year-round visual interest; often multi-trunked, but can be trained to a single stem; scarlet fall color; slow growing; disease and pest resistant
Acer palmatum Japanese maple	Partial shade/Sun	15-25 feet/ 10-25 ft. spread	4 feet +	Prefers moist, well-drained soils; deciduous; slow to moderate growth rate; multi-trunked with spreading branches; intolerant of inundation but moderately drought resistant; vibrant fall colors; many cultivars available including 'Emperor I', 'Katsura', and 'Osakazuki'
Acer platanoides 'Globosum' Globe Norway maple	Sun/partial shade	15-20 feet/ 15-20 ft. spread	4-5 feet +	Moist soils preferred, but tolerates drought and seasonal inundation; tolerant of urban pollution; dense, compact, round form; slow-growing deciduous tree with brilliant fall color; shallow root system may make mowing under the tree slightly difficult; good selection for locations under power lines; another cultivar well suited for such a location is *A. platanoides* 'Almira,' reaching only 20-25 ft.
Acer triflorum Roughbark maple	Sun/partial shade	25-30 feet/ 20-25 ft. spread	Check with jurisdiction	Deciduous; prefers moist soils, but somewhat drought tolerant once established; apricot and gold fall color; rough, knobby trunk provides interest in winter; disease and pest resistant; non-aggressive roots do not damage sidewalks or driveways
Acer truncatum Purpleblow maple	Sun	20-25 feet/ 20-25 ft. spread	5 feet	Prefers moist, well-drained soil, but drought tolerant; very cold hardy deciduous tree; moderate growth rate; yellow flowers in spring; an additional maple cultivar of interest is 'Pacific sunset'

Species/ Common Name	Exposure	MatureHt./ Spread	Planting Strip Width	Comments
Amelanchier x *grandiflora* 'Autumn Brilliance' Serviceberry	Sun/partial shade	20-25 feet/ To 15 ft. spread	4 feet +	Moist to dry, well-drained soils; shrub or small tree; drought tolerant; white clustered flowers in spring; red or yellow fall color; also try 'Princess Diana' for bright red fall color and the slightly taller 'Robin Hill' (20-30 feet)
Carpinus caroliniana American hornbeam	Sun/partial shade	20-30 feet/ 20-30 ft. spread	4-6 feet	Deciduous; prefers moist, rich soils; grows near saturated areas but is only weakly tolerant of saturation; blooms March-May; slow growing; deep coarse laterally spreading roots; medium life span; also consider *Carpinus japonica* (Japanese hornbeam)
Cercis Canadensis Eastern redbud	Partial shade/sun	25 feet/ 30 ft. spread	4 feet +	Deciduous; prefers moist, rich soils; tolerant of shade; somewhat drought resistant, but not in full sun; purple-lavender flowers; medium longevity; often multi-trunked; shallow, fibrous roots become deeper on drier sites; fairly short-lived; blooms March-May
Cornus kousa var. 'Chinensis' Chinese kousa dogwood	Sun/partial shade	To 20 feet/ To 20 ft. spread	3 feet +	Prefers moist soils; tolerant of varying soil types; moderate growth rate; deciduous; white flowers in June and large red fruits that resemble a raspberry in September; red to maroon fall color; more disease resistant than other dogwoods; many additional cultivars available
Crataegus x *lavalii* Lavalle hawthorn	Sun	To 25 feet/ 15-20 ft. spread	4-5 feet	Deciduous; prefers moist, well-drained soil, but tolerant of varying soil types; bronze and coppery red fall color; white flowers in spring; fruit can be a bit messy
Malus spp. Flowering crabapple	Sun/partial shade	15-25 feet/ 6-15 ft. spread	4-5 feet	Tolerant of prolonged soil saturation; somewhat untidy; short lived; tolerant of drought and seasonally saturated soils; deciduous; white or faintly pink flowers in spring; numerous *Malus* species and cultivars provide a variety of foliage and flower colors, forms, and fruit. Many cultivars and varieties available including *M.* 'Adirondack' (to 10 ft. height), *M. floribunda* (Showy crab); *M.* 'Sugar Tyme' (to 18 ft. height); native *M. fusca** (Pacific crabapple) reaches 30-40 ft in height
Parrotia persica Persian ironwood	Sun/light shade	15-35 feet/ 15-30 ft. spread	4 feet	Moist to dry soils; drought tolerant when established, deciduous tree with moderate growth rate; brilliant fall color; often multi-trunked, but can be trained to have just one; tolerates urban pollution and soil compaction; surface roots do not generally cause problems; virtually disease and pest-free
Prunus serrulata 'Shirofugen' Japanese flowering cherry	Sun	To 25 feet/ To 25 ft. spread	4 feet	Deciduous flowering tree; moist, well-drained soils; double pink to white blooms in spring; vigorous grower; additional desirable choices include *P. serrulata* 'Snowgoose', 'Kwanzan', and 'Shirotae'
Quercus ilex Holly oak	Sun/partial shade	20+ feet/ 20 ft. spread	5 feet +	Prefers moist soils, but grows in varying soils; hearty, slow-growing evergreen tree; light pink flowers May-June; pruning will keep tree small for a hedge, without pruning may grow considerably larger – not appropriate under utility lines; tolerates salt water spray

MEDIUM TREES (30 to 50 feet in height)

Space evenly every 25 to 35 feet

Species/ Common Name	Exposure	Mature Ht./ Spread	Planting Strip Width	Comments
Acer platanoides 'Columnare' Columnare Norway maple	Sun/partial shade	40-50 feet/ 15-20 ft. spread	5-6 feet	Deciduous; adapts to varying soils; upright or columnar in form making this cultivar a better choice for narrow locations; tolerant of drought and seasonal inundation; tolerates urban pollution and displays brilliant fall color; shallow rooting necessitates locating at least 4-6 feet from sidewalks and driveways to prevent heaving of pavement
Acer rubrum Red maple	Sun/partial shade	35-50 feet/ 15-40 ft. spread	5-6 feet	Deciduous tree known for fall color; prefer wet or moist soils; tolerant of summer drought and urban pollutants; fast growing with roots that may heave sidewalks or interfere with mowing; many cultivars of varying heights available including: *A. rubrum*, 'Armstrong,' Bowhall', Karpick,' 'Scarsen,' and 'Red Sunset'
Carpinus betulus European hornbeam	Sun/shade	40-60 feet/ 30-40 ft. spread	5 feet	Deciduous tree; tolerant of urban pollution and poor soils; can also be used as a hedge or screen cultivars available and suggested include 'Fasigiata' (30-40 ft. height) and 'Franz Fontaine' (30-35 ft height)
Fraxinus americana 'Autumn Applause' Ash	Sun	To 40 feet/ 25 ft. spread	5-6 feet	Deciduous; prefers moist, well-drained soils; dense, wide spreading canopy; long-lived; purple fall color; moderate growth rate; also try *F. Americana* 'Junginger'
Fraxinus oxycarpa Raywood ash	Sun	25-50 feet/ 25 ft. spread	5 feet +	Deciduous; drought and variable soil tolerant; can take extreme temperatures; does not tolerate constant wind or fog; resists pests and disease better than do other ashes; inconspicuous flowers in spring
Fraxinus pennsylvanica Green ash/red ash	Sun	To 50 feet/ To 40 ft spread	4-5 feet +	Deciduous; prefers moist soils; fast growth rate; tolerant of wind, salt, seasonal drought and urban pollution; numerous cultivars including Patmore' (50-60 ft. height), 'Summit' (to 45 ft. height), and 'Urbanite' (to 50 ft. height)
Ginkgo biloba 'Autumn Gold' Maidenhair tree	Partial sun/partial shade	25-50 feet/ 25-30 ft. spread	5-6 feet	Moist soils; deciduous ornamental tree; fast growing and long-lived; tolerant of urban pollution, summer drought and winter inundation; showy fall color; grows in soils of varying quality; provides dense canopy; additional cultivars available
Gleditsia triacanthos inermis 'Shademaster' Thornless honeylocust	Sun/partial shade	To 45 feet/ 35 ft. spread	5-6 feet	Deciduous; prefers moist, rich soils, but will grow in varying soil types; a thornless cultivar tolerant of drought and seasonal inundation; adapts to urban pollution and displays vigorous growth; deciduous tree with showy yellow fall color; additional cultivars available such as 'Imperial,' which grows 30-35 feet, 'Moraine,' and 'Rubylace'
Koelreuteria paniculata Goldenrain tree	Sun/partial sun	20-35 feet/ 10-30 ft. spread	4 feet +	Deciduous; prefers moist well-drained soils, but is tolerant of poor soils; medium rate of growth and longevity; tolerant of periods of drought and seasonal inundation; tolerates urban pollution; provides a dense, wide-spreading canopy

Species/ Common Name	Exposure	Mature Ht./ Spread	Planting Strip Width	Comments
Platanus x *acerifolia* 'Liberty' London planetree	Sun	To 50 feet/ 45 ft. spread	8 feet	Prefers moist, rich soils, but tolerant of a variety of soils; tolerant of seasonal drought and inundation, urban pollution and poor soils; deciduous tree resistant to sycamore anthracnose, powdery mildew, and inward spread of wood decay due to trunk wounds; patchy ornamental bark; pruning of lower branches may be required for visibility; shallow roots can cause uplifting of sidewalks and pavement - use care when locating near pavement; also try 'Bloodgood' and 'Yarwood'
Pyrus calleryana 'Chanticleer' Flowering pear	Sun	To 40 feet/ 15 ft. spread	4-5 feet	Deciduous tree that grows well in a variety of soil types; orange to reddish fall color; white flowers in spring; additional cultivars of interest include *P. calleryana* 'Redspire' and 'Aristocrat'
Tilia cordata Littleleaf linden	Sun	30-50 feet/ 30 ft. spread	5-6 feet	Deciduous; prefers moist, well-drained soils, but tolerant of a variety of soil types; tolerant of wind and urban pollution; fast growing and long-lived; tolerates summer drought and seasonal inundation; provides a dense canopy; *C. cordata* is the hardiest linden; many forms available including, *T. cordata* 'Chancellor', 'Corzam', and 'Greenspire'

LARGE TREES (50 feet+ in height)

Space evenly every 35 to 45 feet

Species/ Common Name	Exposure	Mature Ht./ Spread	Planting Strip Width	Comments
*Abies grandis** Grand Fir	Sun/partial shade	100 feet/ 40 ft. spread	Check with jurisdiction	Evergreen; tolerant of fluctuating water tables and floods; medium rate of growth; root structure depends on site conditions – shallow in moist areas, deep taproot in drier conditions
Acer platanoides 'Emerald Queen' Emerald Queen Norway maple	Sun/partial shade	To 50 feet/ 40 ft. spread	5-8 feet	Deciduous; fast growing with an erect, spreading form; prefers moist soils, but is tolerant of summer drought and seasonal inundation; tolerates urban pollution; avoid locating near structures due to shallow, vigorous rooting; additional cultivars available including *A. platanoids* 'Parkway'
Acer pseudoplatanus Sycamore maple	Sun/partial shade	40-60 feet/ 25-40 ft. spread	5-8 feet	Deciduous; prefers moist, well-drained soils but is adaptable to may soil types; tolerates summer drought and seasonal inundation; tolerant of urban pollution with a moderate growth rate; sturdy, resistant to wind and salt spray; a number of cultivars are available including: *A. pseudoplatanus* 'Atropurpureum,' ' Brilliantissimum,' 'Cox' (Lustre), and 'Puget Pink'
Acer saccharum Sugar maple		60-75 feet/ 35 ft. spread	6 feet +	Deciduous; prefers moderately moist, well-drained soils; long-lived and tolerant of urban pollutants; slow to medium growth rate; needs large planting area; yellow and orange fall color; a variety of cultivars available including *A. saccharum* 'Legacy'
*Calocedrus decurrens** Incense cedar	Sun/partial shade	75-90 feet/ 10-20 ft. spread	Check with jurisdiction	Evergreen; tolerant of poor soils; drought tolerant after established; tolerant of wind and urban conditions; narrow growth habit makes this a good choice for smaller spaces and ideal for screening, fragrant tree; slow growing and long-lived
Cedrus deodara Deodar cedar		40-60 feet/ 20-40 ft. spread	Check with jurisdiction	Evergreen; prefers moist, well-drained soils, but drought tolerant when established; fairly fast growing and long-lived; dense, wide spreading canopy; attractive cultivars available
*Fraxinus latifolia** Oregon ash	Sun/partial shade	40-80 feet/ 30 ft. spread	6 feet +	Deciduous; saturated, ponded or moist soils; flood tolerant; small green-white flowers; tolerant of poor soils
Gleditsia triacanthos inermis Thornless honeylocust	Sun/partial shade	60-70 feet/ 40 ft. spread	5-6 feet	Deciduous; prefers moist soils, but will grow in poor soils; tolerant of drought, seasonal inundation, and urban pollution; occasionally fruit pods can create litter during winter months; thornless; cultivars available (see *G. triacanthos inermis* 'Shademaster' below in Medium trees)
Metasequoia glyptostroboides Dawn redwood	Sun	70-100 feet/ 25 ft. spread	5 feet +	Deciduous; prefers moist, deep, well-drained soils, but tolerates compacted and poor soils; long-lived, fast growing conifer; tolerant of seasonal inundation and drought; can grow in standing water; needles turn russet in the fall; needs large growing area; lower growing cultivars available such as *M. glyptostroboides* 'Gold Rush' and 'Sheridan Spire'

Species/ **Common Name**	**Exposure**	**Mature Ht./ Spread**	**Planting Strip Width**	**Comments**
Picea omorika Serbian spruce	Sun/partial shade	50-60 feet/ 20-25 ft. spread	Check with jurisdiction	Slow growing; tolerant of varying soils and urban pollution; moderately drought tolerant once established; elegant evergreen spruce, good for narrow locations; lower growing cultivars available
*Pseudotsuga menziesii** Douglas fir	Sun to shade	75-120 feet/ 40 ft. spread	Check with jurisdiction	Evergreen conifer; moist to dry soils; long-lived with a medium to fast rate of growth; tolerant of summer drought, winter inundation, and poor soils; withstands wind and urban pollution; provides a nice canopy, but potential height will restrict placement
Quercus bicolor Swamp white oak	Sun	60 feet/ 45 ft. spread	6-8 feet	Deciduous; grows in wet or moist sites, but is tolerant of drought conditions; withstands poorly drained soils; long-lived with moderate rate of growth
Quercus coccinea Scarlet oak	Sun	50-60 feet/ 45 ft. spread	6-8 feet	Deciduous; grows in a variety of soil types; long-lived with a moderate growth rate; tolerant of summer drought and urban pollution; does not tolerate saturated soils or shade; brilliant scarlet to red fall foliage
Quercus macrocarpa Burr Oak	Sun	70-80 feet/ 30-40 ft. spread	8 feet	Prefers moist soils, but is adaptable to varying soils; slow growing and long-lived; rugged looking deciduous tree; tolerant of seasonal drought and inundation; tolerates urban pollution and city conditions; provides a wide-spreading, dense canopy
Quercus phellos Willow oak	Sun/partial shade	60-70 feet/ 50 ft. spread	6 feet	Deciduous; prefers moist, well-drained soils, but grows in a wide range of soils types; long-lived tree with moderate growth rate and fibrous root system; tolerant of seasonal drought and inundation, as well as urban pollution; provides a wide-spreading, dense canopy; small delicate leaves
Quercus robur English oak	Sun	40-60+ feet/ 40 ft. spread	4-8 feet	Prefers well-drained soil; slow to moderate growth rate; long-lived deciduous tree; tolerant of seasonal drought and inundation; tolerates urban pollution, poor soils and constrained root space; susceptible to powdery mildew; many varieties and cultivars available including: 'Concordia,' 'Fastigiata,' 'Foliis Variegatis, and 'Westminster Globe.'
Quercus rubra Northern red oak	Sun/partial shade	60-75 feet/ 50 ft. spread	6-8 feet	Prefers moist, well-drained soils, but drought tolerant when established; tolerates seasonal inundation, urban pollution and salt spray; moderate rate of growth and longevity; provides a dense, wide-spreading canopy; susceptible to oak wilt fungus
Quercus shumardii Shumard's oak	Sun	To 70 feet/ 50 ft. spread	8 feet	Prefers moist, well-drained soils; deciduous, long-lived tree; tolerant of seasonal drought and inundation, urban pollution and poor soils
Taxodium distichum Bald cypress	Sun/partial shade	To 75 feet/ 40 ft. spread	Check with jurisdiction	Deciduous conifer; wet, mucky soils; tolerant of summer drought and seasonal flooding; will grow in poor soils; slow growing; long-lived with a wide-spreading canopy; roots do not appear to lift sidewalks as readily as other species; prune lower branches for sight-lines; cultivars include *T. distichum* 'Shawnee Brave'

Species/ Common Name	Exposure	Mature Ht./ Spread	Planting Strip Width	Comments
*Thuja plicata** Western red cedar	Partial shade/ shade	200 + feet/ 60 ft. spread	Check with jurisdiction	Moist to swampy soils; evergreen tree tolerant of seasonal flooding and saturated soils; a good tree for screening; long-lived; cultivars 'Pumilio' and 'Cuprea' are shorter versions, 'Aurea' and 'Atrovirens' have distinctive foliage
Tilia platyphyllos Bigleaf linden	Sun	60-80 feet/ 60 ft. spread	Check with jurisdiction	Prefers moist, well-drained soils, but grows in a variety of soil types; deciduous tree with medium growth rate; long-lived; tolerant of seasonal drought and inundation; tolerates urban pollutants; provides a wide-spreading, dense canopy; yellowish-white flowers attract bees
Ulmus ssp. Elm hybrids	Sun	50-60 feet/ 35-50 ft. spread	6-8 feet	Deciduous; prefers moist, well-drained soils, but drought tolerant; rapid grower; attractive yellow fall color; a hybrid elm resistant to Dutch elm disease; suggested hybrids include 'Accolade', 'Homestead' and 'Pioneer'
Umbellularia californica Oregon myrtle	Sun/partial shade	40-75+ feet/ To 50 ft. spread	Check with jurisdiction	Prefers moist, well-drained soils; slow growing evergreen tree with aromatic leaves; tolerates seasonal drought and inundation; tolerant of urban pollution; provides a wide-spreading, dense canopy; resistant to pests and disease; good for tall hedges or, when trunks are thinned, as a street tree; requires summer watering until established

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Appendix 2
Bioretention Design Examples

The following examples, from different locations in the U.S., illustrate a variety of concepts and specifications useful for developing bioretention facilities specific to local needs.

1. Bioretention Cell: Prince George's County, Maryland

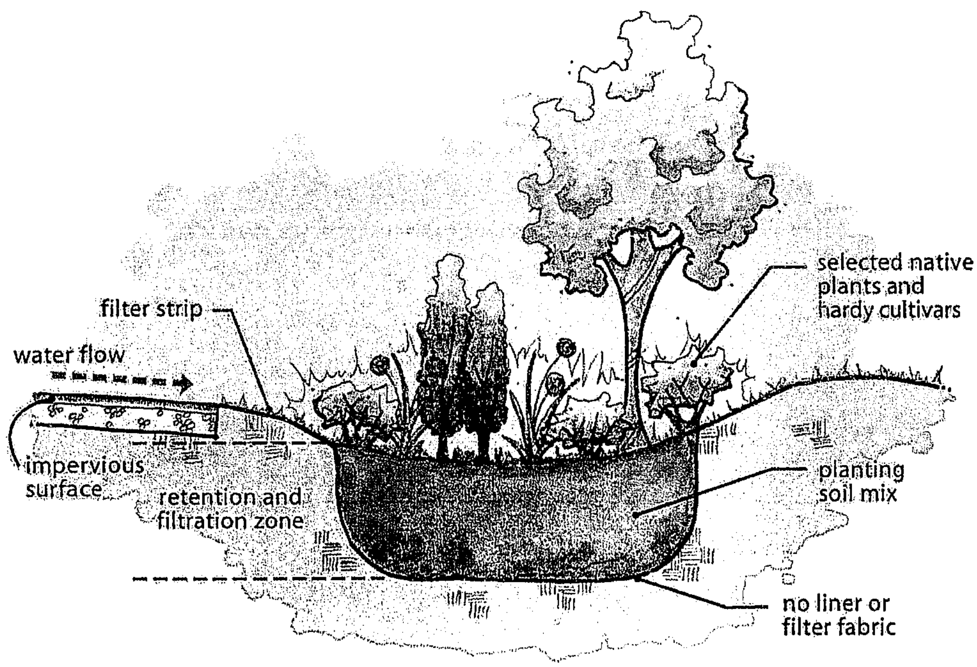

Figure 1 Typical bioretention design section.
Graphic by AHBL Engineering

Type of facility

- General application for infiltration and recharge, not recommended for contaminant hotspots.
- The initial bioretention design applied in the U.S. and the most simple design type.

Contributing area: 1-acre maximum with a maximum of ½-acre impervious area recommended.
Sizing: modified TR 55.
Flow path: off-line preferred, in-line permitted.
Planting soil depth: 2.5 feet minimum—allows for adequate filtration above native soil.

Soil:

Native soil (outside of excavated area)

- Minimum infiltration rate of 1 inch/hour.

Planting soil mix

- 50 to 60% sand, 20 to 30% leaf compost, and 20 to 30% topsoil.
- Infiltration rate not reported; however, recommended porosity for soil mix is approximately 25%.
- Topsoil is sandy loam, loamy sand or loam texture (USDA texture triangle).
- Maximum clay content < 5%.
- pH range 5.5 to 6.5.
- Uniform mix free of stones, stumps, roots or other similar material > 2 inches.
- Clean sand (0.02 to 0.04 inches) meeting AASHTO M-6 or ASTM C-33.

Comments

This is the initial planting soil specification developed for bioretention areas in the early 1990s and has been successfully applied in facilities operating for the past 10 years.

Pretreatment: provide grass or vegetated strip if space allows.

Under-drain: none

Gravel blanket: none

Filter fabric: none unless placed along sides to reduce lateral flows under adjacent pavement areas (e.g. median strip or parking lot island).

Mulch:

- 3-inch maximum, well-aged (12 months min.) shredded hardwood (shredded minimizes floating of material during surface water ponding), use fresh bark mulch when additional nitrogen retention desirable.

Compaction:

- Place soil in lifts of 12 to 18 inches.
- Do not use heavy equipment in bioretention basin.
- If compaction occurs at bottom of facility during excavation, rip to a minimum 12 inches and till 2 to 3 inches of sand into base before backfilling.
- If final grading of soil mix cannot be accomplished by hand, use light, low ground-contact pressure equipment.

Surface pool dewater: 3 to 4 hours.

System dewater: less than 48 hours.

Max ponding depth: 6 inches.

(Prince George's County, 2002)

2. Bioretention cell: Prince George's County, Maryland

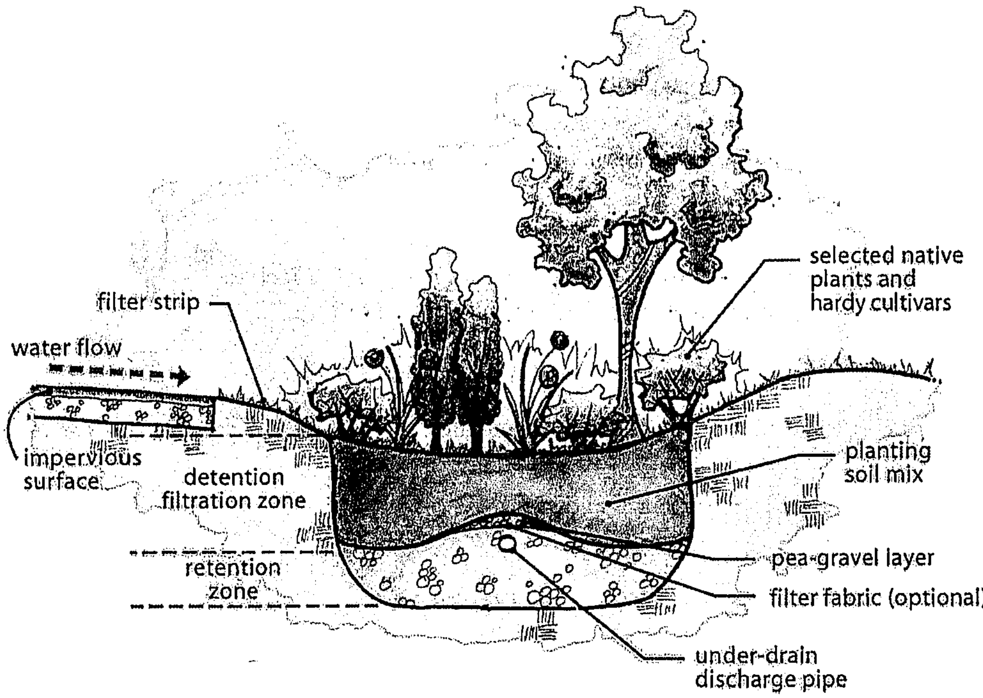

Figure 2 Bioretention design with elevated under-drain and fluctuating aerobic/anaerobic zone.
Graphic by AHBL Engineering

Type of facility:

- General application for infiltration, filtration, and recharge where high nitrogen loadings are anticipated.
- Design allows for a fluctuating aerobic/anaerobic zone below the raised under-drain discharge pipe.
- Design can be used for contaminant hotspot areas with liner.

Contributing area: 2-acre maximum with a maximum of 1-acre impervious area recommended.

Sizing: modified TR 55.

Flow path: off-line preferred, in-line permitted.

Planting soil depth: 2.5 feet minimum

Soil:

Native soil (outside of excavated area)

- Minimum infiltration rate can be less than 1 inch/hour with under-drain.

Planting soil (see Example #1)

Pretreatment: provide grass or vegetated strip if space allows.

Under-drain:

- 6 to 8-inch diameter rigid schedule 40, ½-inch perforations, 6 inches center to center.

Gravel blanket:

- Under-drain gravel bed: ½ to 1½-inch diameter washed stone AASHTO M-43.
- Pea gravel diaphragm (placed between planting soil and drain rock for improved sediment filtration): ¼ to ½-inch diameter washed stone ASTM D 448, 3 to 8 inches thick.

Filter fabric:

- Non-woven ASTM D-4491, permittivity 75 gal/min/ft^2 minimum, installed horizontally on top of the drain rock extending 1 to 2 feet either side of under-drain pipe located below.
- Filter fabric on bottom or sides of facility is not recommended unless used to restrict lateral or vertical flow.
- If pea gravel diaphragm is used, filter fabric can be placed between drain rock and diaphragm to impede direct gravitational flow.

Mulch:

- 3-inch maximum, well-aged (12 months min.) shredded hardwood (shredded minimizes floating of material during surface water ponding), use fresh bark mulch when additional nitrogen retention desirable.

Surface pool dewater: 3 to 4 hours.

System dewater: less than 48 hours.

Max ponding depth: 6 inches.

(Prince George's County, 2002)

3. Bioretention Swale: Seattle Public Utilities (SEA Street project)

Figure 3 SEA Street bioretention swale. *Photo by Colleen Owen*

Type of facility: Redesign of 660-foot existing street using bioretention swales within right-of-way for infiltration and conveyance.

Construction date: 1999 to 2000.

Contributing area: 2.3 acres (approximately 35% total impervious area).

Sizing: Santa Barbara Unit Hydrograph.

Flow path: in-line.

Planting soil depth: approximately 1 foot.

Soil:

Native soil

- Heterogeneous till-like material (not true lodgement till) with lens of silt, sand, and gravel material of varying permeability.

Planting soil

- Bottom of swales: 50% approved native soil and 50% decomposed organic compost by volume, thoroughly mixed. Remaining areas: 70 to 75% approved native soil and 25 to 30% compost by volume, thoroughly mixed.
- Infiltration rate not reported.

Comments

This soil specification has proven successful for infiltration requirements and plant growth and health at the SEA Street project; however, Seattle has modified the specification as noted in the Broadview Green Grid project (see example #4).

Pretreatment: none.

Under-drain:

- 6- to 8-inch slotted PVC pipe with surface drains set at designed flow depth elevations, solid iron pipe under driveways.
- Ultimate outfall to existing roadside ditch at end of block.
- Some areas lined with clay to restrict infiltration and possible subsurface flow to residential basements.

Gravel blanket: Seattle type 26 (sand gravel mix, see Section 6.1.2.3 Bioretention components for specification).

Filter fabric: none.

Mulch: 3-inch depth minimum (same as compost used for soil mix).

Compaction:

- No heavy equipment allowed in bioretention swale area during construction.
- No excavation during wet or saturated conditions.
- Soil installed in maximum lifts of 6 inches and foot compacted.

Surface pool dewater: not available.

System dewater: not available.

Max ponding depth: Live storage: 12 inches. Dead storage: 0 inches.

(Tackett, 2004; Seattle Public Utilities, 2000; personal communication, Tracy Tackett 2004)

4. Bioretention Swale: Seattle Public Utilities (Broadview Green Grid project)

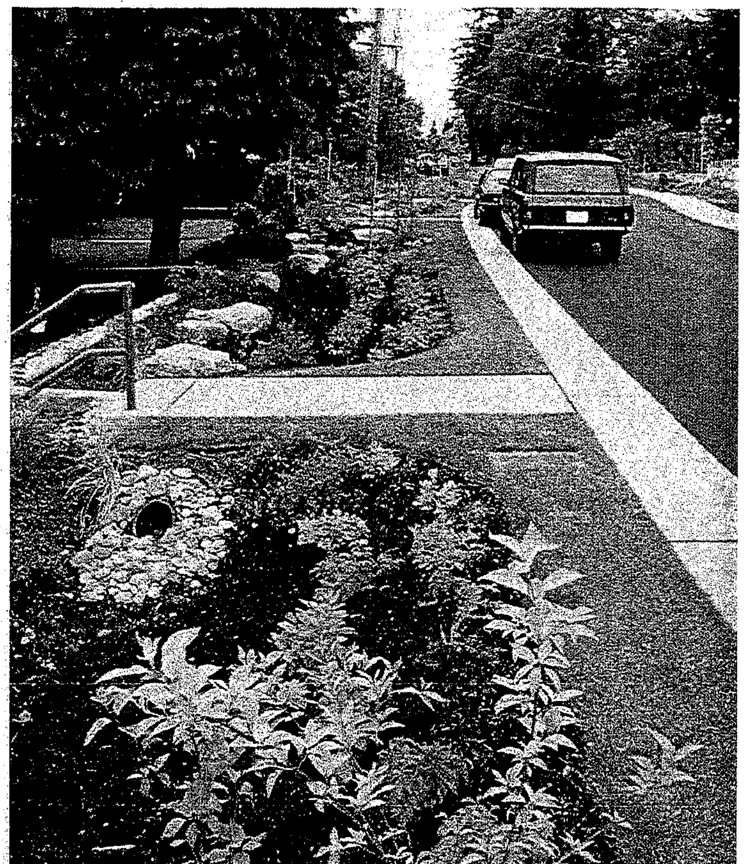

Figure 4 Broadview green grid bioretention swale. *Photo courtesy of Seattle Public Utilities.*

Type of facility: Redesign of existing streets using bioretention swales within right-of-way for infiltration and conveyance (several blocks in length).

Construction date: 2003 to 2004.

Facility depth: 1 to 2.5 feet.

Contributing area: 2.9 to 3.7 acres (34 to 42% TIA) plus 32 acres (34% TIA) east-west streets. North-south street shown in Figure 4.

Sizing: XP-WSM

Flow path: in-line.

Soil:

Native soil (outside excavation area)

- C soils (SCS)

Planting soil mix

- Three different soil mixes are used in the Broadview Green Grid project depending on required infiltration rate, load bearing, and timing of installation.

1. Engineered Soil Mix

The Engineered Soil Mix is used in bioretention swale areas where higher infiltration rates and additional detention is desired. This mix is also used in road shoulder areas adjacent to bioretention/swales and is expected to maintain relatively good infiltration rates at 85% to 90% compaction.

- Design infiltration rate: 2 inches/hour.

Soil mix:

- 65% to 70% gravelly sand and 30% to 35% compost (see specification below).
- Gravelly sand gradation per ASTM D 422:

Sieve size	Percent Passing
2-inch	100
¾-inch	70-100
¼-inch	50-80
US No. 40	15-40
US No. 200	0-3

- The soil mixture should be uniform, free of stones, stumps, roots or other similar objects larger than 2 inches.
- On-site soil mixing or placement not allowed if soil is saturated or subject to water within 48 hours.
- Cover and store soil accordingly to prevent wetting or saturation.
- Test soil for fertility and micronutrients and, if necessary, amend mixture to create optimum conditions for plant establishment and early growth at rates recommended by an independent laboratory soil test.
- Place soil in lifts not exceeding 6 inches.

Comments

This soil specification maintains a higher infiltration rate at typical compaction rates. While the city of Seattle anticipates good performance from this specification, the mix may be slightly less optimum for plant growth than bioretention soil mixes 1 and 2 (see specification below) and has not been tested long-term for plant health performance.

2. Bioretention Soil Mix 1

Bioretention Soil Mix 1 uses on-site excavated soil mixed with compost.

Design infiltration rate: 0.3 to 1.0 inch/hour (varies with properties of native soils).

Soil mix:

- Approximately 65% approved on-site soil and 35% compost material thoroughly mixed.
- Excavated soil for mixing should be free of large woody debris or garbage (concrete or asphalt chunks, old pipe, etc.).
- Collect and test representative samples of excavated soil for gradation.
- Using on-site excavated soil is not appropriate for on-site soils with high clay content. The excavated soil should be sandy loam, loamy sand or loam texture (USDA texture triangle). The excavated soil can be amended with appropriate aggregate (e.g. sand) to achieve the appropriate texture.
- Cover and store soil accordingly to prevent wetting or saturation.
- Test soil for fertility and micronutrients and, if necessary, amend mixture to create optimum conditions for plant establishment and early growth at rates recommended by an independent laboratory soil test.
- Organic content of the soil mixture should be 8% to 12%.

Comments

On-site excavated soil, rather than imported soil, is specified as part of an overall sustainability strategy for Seattle. Using on-site excavated soil for the amended soil mix may reduce control over gradation, organic content, and final product performance, can increase project costs, and can complicate construction logistics when attempting to blend soil mix components in restricted space (personal communication, Tracy Tackett, 2004).

3. Bioretention Soil Mix 2

Bioretention Soil Mix 2 is mixed off-site and delivered ready for installation.

Design infiltration rate: 1 inch/hour.

Soil mix:

- 65% to 70% gravelly sand and 30% to 35% compost (see specification below).
- Gravelly sand gradation per ASTM D 422.

Sieve size	Percent Passing
US No. 4	100
US No. 6	88-100
US No. 8	79-97
US No. 50	11-35
US No. 200	5-15

- Maximum clay content should be less than 5%.
- Soil mixture should be uniform, free of stones, stumps, roots or other similar objects larger than 2 inches.
- On-site soil mixing or placement not allowed if soil is saturated or subjected to water within 48 hours.
- Cover and store soil accordingly to prevent wetting or saturation.
- Test soil for fertility and micronutrients and, if necessary, amend mixture to create optimum conditions for plant establishment and early growth at rates recommended by an independent laboratory soil test.
- Organic content of the soil mixture should be 8% to 12%.

Comments

The city of Seattle uses soil mix 2 during the wet season when maintaining dry native soil for mixing on-site is difficult. Bioretention soil mix 2 is a "vegetable garden mix" supplied by Cedar Grove Composting of Washington.

Compost material (for all 3 soil mixes)

- Material must be in compliance with WAC chapter 173-350 section 220 and meet Type 1, 2, 3 or 4 feedstock.
- See Section 6.2: Amending Construction Site Soils for compost specification.

Pretreatment: none.

Under-drain:

- 6 to 8-inch slotted PVC pipe, solid iron pipe under driveways.
- Under-drains connected to next downstream swale.

Gravel blanket: Seattle type 26 (sand gravel mix, see Section 6.1: Bioretention Areas for specification).

Filter fabric: none.

Mulch: 3-inch depth minimum. Compost used for mulch in bottom of swale and shredded tree trimmings in surrounding areas.

Compaction:

- No heavy equipment allowed in bioretention/swale area during construction.
- No excavation during wet or saturated conditions.
- Soil installed in maximum lifts of 6 inches and foot compacted.

Surface pool dewater: 24 hours.

System dewater: not reported.

Max ponding depth: 12 inches (total live and dead storage).

(Tackett, 2004; personal communication Tracy Tackett, 2004)

5. Sloped Bio*detention*: Austin, Texas

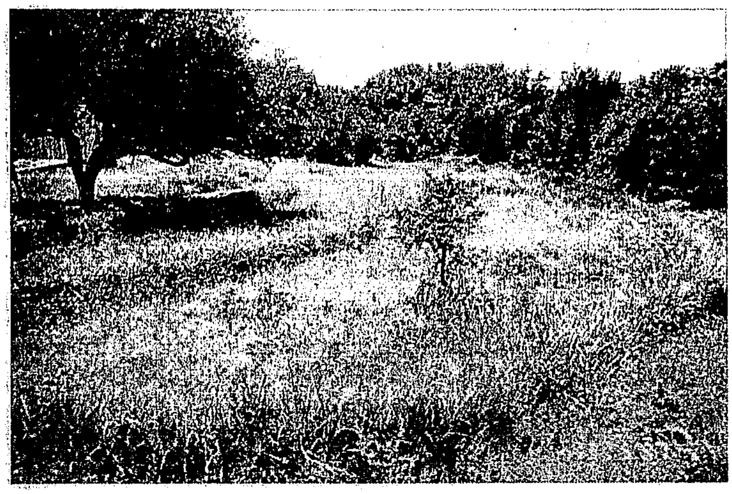

Figure 5 This sloped biodetention facility was a more cost-effective design for an Austin, Texas subdivision than a conventional pond. *Photo courtesy of Murphee Engineering.*

Type of facility: sloped biodetention using grassy vegetative barriers (hedgerows) on contour to detain storm flows and reduce pollutant loads.

Contributing area: not known.

Flow path: in-line.

Planting soil depth: 12-inch deep by 8-inch wide trenches excavated for planting vegetated barriers.

Soil:

Native soil

- C and D soils (SCS) on Karst formations.
- Infiltration rate not reported.

Planting soil:

- Native soil with slow release fertilizer.
- Infiltration rate not reported.

Pretreatment: rock berm used as a level spreader to distribute and release flow across slope and vegetative barriers down slope.

Under-drain: none.

Gravel blanket: not applicable.

Filter fabric: none.

Mulch: none.

Hedge plantings:

- Alamo switchgrass (*Panicum zizanioides*) in 8-inch wide rows on contour.
- Species should be adapted to local soil and climate conditions, easily established, long-lived, as well as have stiff stems that remain erect through the year. Grass species that can emerge through sediment deposits and resume growth from buried stem nodes, rhizomatous or stoloniferous growth habit are desired (Natural Resources Conservation Service, 2001).
- First row receiving discharges is double planted (one row a few inches down slope of the first row) using 4-inch slips on 4-inch centers.
- Planted at 110 stems per square foot.
- Area between hedgerows planted in grass for slope and soil stability and additional filtering.

Spacing: 25 feet between hedgerows (2 to 2.5% slope). Spacing will depend on slope.

Sizing and Hedgerow length:

- 2-year design storm (2.64 inches/3 hours) used for sizing.
- Hedgerows designed to manage 0.2 cfs discharge from contributing area per foot of hedgerow.

(Murphee, Scaief and Whelan, 1997)

Appendix 3

Bioretention Plant List

The following table includes both native and non-native plant species commonly available in the Puget Sound region and suitable for bioretention cells and swales. Individual site characteristics and goals may exclude some species or require modifications or additions to plant suggestions provided here.

Bioretention cells and swales generally feature three planting zones characterized by soil moisture and periodic inundation.

Zone 1: Area of periodic or frequent standing or flowing water. Zone 1 plants will also tolerate the seasonally dry periods of summer in the Pacific Northwest without extra watering and may also be applicable in zone 2 or 3.

Zone 2: Periodically moist or saturated during larger storms. Plants listed under Zone 2 will also be applicable in Zone 3.

Zone 3: Dry soils, infrequently subject to inundation or saturation. This area can be used to transition or blend with the existing landscape.

Special Considerations

Drought tolerance–Several plants included on the list do not tolerate dry conditions. For these plants, irrigation will be necessary during dry periods. In general, all plantings require watering during dry periods for the first two or three years after planting until established.

Placement of large trees–Consider height, spread, and extent of roots at maturity. Use caution in plant selection for areas with under-drain pipes or other structures. Lower limbs of plants placed close to a road or driveway may cause problems with visibility or safety. See Appendix 1: Street Trees for more information on tree selection and placement suggestions.

Phytoremediation–Appendix 5 includes a list of plants that have been studied for their ability to filter, absorb, and/or degrade specific contaminants. While most of these plants are not included in the following lists, varieties of some of the species known for phytoremediation are listed.

▶ ZONE 1

* denotes native species

TREES

Species/ Common Name	Exposure	Mature Size/ Spread	Time of Bloom	Comments
*Alnus rubra** Red alder	Sun/partial shade	30-120 feet/ 25 ft. spread		Prefers moist, rich soils, highly adaptable, drought tolerant; nitrogen fixer; rapid growing, relatively short-lived (60-90 years)
*Fraxinus latifolia** Oregon ash	Sun/partial shade	40-80 feet/ 30 ft. spread		Moist, saturated or ponded soils; flood tolerant; small green-white flowers
*Malus fusca** Pacific crabapple	Sun/partial shade	To 40 feet/ 35 ft. spread	Spring	Tolerant of prolonged soil saturation; produces fruit (do not plant near public walkways)
*Salix lucida** Pacific willow	Sun	40-60 feet/ 30 ft. spread		Wet soils; tolerates seasonal flooding; should not be planted in areas near pavement or underground structures

SHRUBS

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Cornus sericea** Red-osier dogwood Red-twig dogwood	Sun/partial shade	To 15 feet	May - June	Prefers wet to moist organically rich soils, but is adaptable; tolerates seasonal flooding; small white flowers; berrylike fruits
Cornus sericea 'Kelseyi' Dwarf dogwood	Sun	To 1.5 feet	June – August	Prefers wet to moist organically rich soils, but is adaptable; small white flowers; berrylike fruit; low growing, compact form; good ground cover
Cornus sericea 'Flaviramea' Yellow dogwood	Sun/partial shade	6-8 feet	May - June	Prefers wet to moist organically rich soils, but is adaptable; easily transplanted and grown; small, white flowers; yellow stems and reddish, purple fall color
Cornus sericea 'Isanti' Isanti dogwood	Sun/partial shade	4-5 feet	May - June	Prefers wet to moist organically rich soils, but is adaptable; deciduous shrub; tiny white flowers; red stems; purple fall color
*Lonicera involucrata** Black twinberry	Partial shade/shade	2-8 feet	April - May	Moist soils; prefers loamy soils; tolerant of shallow flooding; yellow, tubular flowers attract hummingbirds
*Myrica californica** Pacific wax myrtle	Sun/partial shade	To 30 feet	May - June	Evergreen shrub preferring moist soils; inconspicuous spring flowers; drought tolerant; if drought tolerance is not an issue try the smaller Washington native, *Myrica gale**
*Physocarpus capitatus** Pacific ninebark	Sun/partial shade	6-13 feet	May - June	Moist or dry soils; drought tolerant; snowball shaped; white flowers; seeds persist into winter
*Rosa pisocarpa** Clustered wild rose	Sun/partial shade	6-8 feet	May - July	Moist soils, tolerates seasonal flooding but also tolerant of dry conditions; pink clustered flowers; fruits persist
Salix purpunea 'Nana' Dwarf Arctic willow	Sun/partial shade	3-5 feet		Grows well in poor soils; moderately drought tolerant; small yellow flowers in the fall
*Spiraea douglasii** Douglas spirea Steeplebush	Sun/partial shade	4-7 feet		Moist or dry, to seasonally inundated soils; spikes of small, pink flower clusters

▶ ZONE 1

EMERGENTS

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Carex obnupta** Slough sedge	Sun/partial shade	1-5 feet		Moist to seasonally saturated soils; shiny foliage; excellent soil binder; drought tolerant
*Carex stipata** Sawbeak sedge	Partial shade	10 inches-3 feet		Wet soils; excellent soil binder
*Juncus effusus** Common rush	Sun/partial shade	1-2 feet	Summer	Wet soils; evergreen perennial; hardy and adaptable; drought tolerant; small, non-showy flowers
*Juncus ensifolius** Daggerleaf rush	Sun	12-18 inches		Wet soils; shallow water; excellent soil binder
*Juncus tenuis** Slender rush	Sun	.5-2.5 feet		Moist soils; tufted perennial
*Scirpus acutus** Hardstem bulrush	Sun	4-8 feet		Wet soils; favors prolonged inundation; excellent soil binder
*Scirpus microcarpus** Small-fruited bulrush	Sun/shade	2-4 feet		Wet soils; tolerates prolonged inundation; good soil binder; drought tolerant

▶ ZONE 2

TREES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Acer truncatum Pacific sunset maple	Sun	To 25 feet/ 20 ft. spread		Prefers moist, well-drained soils, but drought tolerant; very cold hardy; deciduous tree with moderate growth rate
*Amelanchier alnifolia** Western serviceberry	Sun/partial shade	10-20 feet/ 25 ft. spread	April - May	Moist to dry, well-drained soils; drought tolerant; large white flowers; purple to black berries; deciduous
*Corylus cornuta** Beaked hazelnut	Sun/partial shade	20-30 feet/ 15 ft. spread	April - May	Moist, well-drained soils; edible nuts; intolerant of saturated soils; catkins throughout winter add interest; deciduous
*Crataegus douglasii** Black hawthorn	Sun/partial shade	3-30 feet/ 25 ft. spread	Spring	Moist to dry, well drained, gravelly soils; small white flowers, black berries; 1" spines; forms thickets; deciduous
Fraxinus oxycarpa Raywood ash	Sun	25-50 feet/ 25 ft. spread	Spring	Drought tolerant; grows in varying soil types; deciduous; can take extreme temperatures; does not tolerate constant wind or fog; resists pests and disease better than other non-native ashes; inconspicuous flowers
*Rhamnus purshiana** Cascara sagrada	Sun/shade	20-40 feet/ 25 ft. spread		Moist to fairly dry soils; small greenish-yellow flowers; deciduous; sensitive to air pollution; yellow fall color
*Salix scouleriana** Scouler willow	Sun/partial shade	6-40 feet/ 15 ft. spread		Moist to dry soils; drought tolerant; deciduous tree; do not plant near paved surfaces or underground structures
*Salix sitchensis** Sitka willow	Sun/partial shade	3-26 feet/ 25 ft. spread		Moist soils; tolerates seasonal flooding; deciduous tree; do not plant near paved surfaces or underground structures
*Thuja plicata** Western red cedar	Partial shade/shade	200 feet+/ 60 ft. spread		Moist to swampy soils; tolerates seasonal flooding and saturated soils; long-lived; prefers shade while young

▶ ZONE 2

SHRUBS - Deciduous

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Acer circinatum** Vine maple	Filtered sun/shade	To 25 feet	Spring	Dry to moist soils; tolerant of shade and clay soils; excellent soil binder; beautiful fall color
Hamamelis intermedia Diane Diane witchhazel	Sun/partial shade	10-20 feet/ 10 ft. spread	January - March	Moist, fertile, acidic soil; showy fall color – yellow to yellow-orange; long-lasting, slightly fragrant, coppery-red flowers; not drought tolerant; may require watering in dry season
*Oemleria cerasiformis** Indian plum/Osoberry	Sun/partial shade	5-16 feet	February - March	Moist to dry soils; prefers shade; tolerates fluctuating water table
Philadelphus x lemoinei 'Belle Etoile' Mock-orange	Sun/partial shade	5-6 feet	May - June	Prefers moist, well-drained soils, high in organic matter, but soil and pH adaptable; easily transplanted and established; fragrant, large white flowers, tinged red at the base; other cultivars available
*Ribes lacustre** Black swamp gooseberry	Partial shade	1.5–3 feet		Moist soils; deciduous shrub; reddish flowers in drooping clusters; dark purple berries; *R. divaricatum** (Wild gooseberry) grows to 5 feet and is also an option; attracts butterflies, but is very thorny
*Rosa nutkana** Nootka rose	Sun/partial shade	6-10 feet	April - June	Moist to fairly dry soils; tolerates inundation and saturated soils; aggressive spreader; fruits persist; less thorny that *R. rugosa*
Rosa rugosa Rugosa rose	Sun	To 8 feet		Drought resistant; hardy, vigorous and aggressive; highly prickly; fragrant white to purple flowers; fruits persist
*Rubus parviflorus** Thimbleberry	Sun/partial shade	4-10 feet	May - June	Moist to dry soils; white flowers; red berries; makes thickets and spreads easily
*Rubus spectabilis** Salmonberry	Partial sun/shade	5-10 feet	February - April	Prefers moist, wet soils; good soil binder; magenta flowers; yellow/ orange fruit; early nectar source for hummingbirds; makes thickets
*Sambucus racemosa** Red elderberry	Partial sun/partial shade	To 20 feet	April - May	Moist to dry soils; small white flowers; bright red berries; vase shaped; pithy stems lead to "messy" form – prune for tidiness
*Symphoricarpos albus** Snowberry	Sun/shade	2-6 feet		Wet to dry soils, clay to sand; excellent soil binder; drought and urban air tolerant; provides good erosion control; spreads well in sun; white berries; flowers attract hummingbirds
*Vaccinium parvifolium** Red huckleberry	Partial shade/shade	4-10 feet		Slightly moist to dry soils; prefers loamy, acid soils or rotting wood; tolerant of dry, shaded conditions; red fruit; tricky to transplant

▶ ZONE 2

HERBACEOUS

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Aquilegia formosa** Western columbine	Sun/partial shade	1-3 feet	Spring	Moist soils of varying quality; tolerant of seasonal flooding; red and yellow flowers attract hummingbirds and butterflies
*Asarum caudatum** Wild ginger	Partial shade/shade	To 10 inches	Mid spring	Moist organic soils; heart-shaped leaves; reddish-brown flowers
*Aster chilensis** Common California aster	Sun	1.5 – 3 feet	June - September	Moist soils; white to purple flowers
*Aster subspicatus** Douglas aster	Sun	.5 – 2.5 feet	June - September	Moist soils; blue to purple flowers
*Camassia quamash** Common camas	Sun/partial shade	To 2.5 feet	May - June	Moist to dry soils; lots of watering needed to establish; loose clusters of deep blue flowers
Camassia leichtlinii Giant camas		2–4 feet	May - June	Moist to dry soils; lots of watering to establish; large clusters of white, blue or greenish-yellow flowers
*Iris douglasiana** Pacific coast iris	Sun/partial shade	1-2 feet	Spring	Tolerates many soils; withstands summer drought and seasonal flooding; white, yellow, blue, reddish purple flowers; fast growing; velvety purple flowers; vigorous
Iris foetidissima Gladwin iris	Sun/partial shade	1-2 feet	May	Moist to dry, well-drained soils; pale lilac flower; also called Stinking Iris
*Juncus tenuis** Slender rush	Sun	6 inches – 2.5 feet		Moist soils; yellow flowers
Iris sibirca Siberian Iris	Sun	1-2.5 feet	Late spring – early summer	Moist soils; deep blue, purple to white flowers
*Tellima grandiflora** Fringecup	Partial sun/shade	1-3 feet	March - June	Perennial preferring moist soils; yellowish-green to pink flowers
*Tiarella trifoliata** Foamflower	Partial sun/shade	To 1 foot	Early - mid summer	Moist soils; perennial with some drought tolerance after established; can form dense colonies; white flowers
*Tolmiea menziesii** Youth-on-age/Piggy-back plant	Partial shade/shade	1-2 feet	April - August	Moist soils; brownish-purple flowers; also makes and effective groundcover
Viola species* Violets	Partial shade/shade	6-12 inches	Late spring – early summer	Moist soils; yellow to blue flowers

▶ ZONE 3

TREES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Arbutus unedo Strawberry tree	Sun/partial shade	8-35 feet/ 8-20 ft. spread	November - December	Tolerant of extremes; tolerant of urban/ industrial pollution; white or greenish white flowers
*Calocedrus decurrens** Incense cedar	Sun	75-90 feet/ 12 ft. spread		Tolerant of poor soils; drought tolerant after established; fragrant evergreen with a narrow growth habit; slow growing
Chamaecyparis obtusa Hinoki false cypress	Sun/partial shade	40-50 feet/ 15-30 ft. spread		Moist, loamy, well-drained soils; very slow growing; prefers sun, but tolerates shade; does not transplant well or do well in alkaline soils. Note there are many alternative varieties of false cypress of varying sizes and forms from which to choose
Cornus spp. Dogwood	Sun/partial shade	20-30 feet/ 30 ft. spread	May	Reliable flowering trees with attractive foliage and flowers; may need watering in dry season; try *C. florida* (Eastern dogwood), or *C. nuttallii** (Pacific dogwood) or hybrid 'Eddie's White Wonder'. Also, *C. kousa* for small tree/ shrub which is resistant to anthracnose
Pinus mugo Swiss mountain pine	Sun/partial shade	15-20 feet/ 25-30 ft. spread		Prefers well-drained soil; slow growing, broadly spreading, bushy tree; hardy evergreen
Pinus thunbergiana Japanese black pine	Sun	To 100 feet/ 40 ft. spread		Dry to moist soils; hardy; fast growing
*Prunus emarginata** Bitter cherry	Sun/partial shade	20-50 feet/ 20 ft. spread	May - June	Dry or moist soils; intolerant of full shade; bright red cherries are attractive to birds; roots spread extensively
Prunus virginiana Choke cherry		15-25 feet/ 15-20 ft. spread	Late spring – Early summer	Dry or moist soils; deep rooting; attractive white fragrant flowers; good fall color
*Pseudotsuga menziesii** Douglas-fir	Sun	100-250 feet/ 50-60 ft. spread		Does best in deep, moist soils; evergreen conifer with medium to fast rate of growth; provides a nice canopy, but potential height will restrict placement
*Quercus garryana** Oregon white oak	Sun	To 75 feet		Dry to moist, well-drained soils; slow growing; acorns

SHRUBS

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Holodiscus discolor** Oceanspray	Sun/partial shade	To 15 feet	June - July	Dry to moist soils; drought tolerant; white to cream flowers; good soil binder
*Mahonia aquifolium** Tall Oregon grape	Sun/partial shade	6-10 feet	March - April	Dry to moist soils; drought resistant; evergreen; blue-black fruit; bright yellow flowers; 'Compacta' form averages 2 feet tall; great low screening barrier
*Philadelphus lewisii** Mock-orange	Sun/partial shade	5-10 feet	June - July	Adapts to rich moist soils or dry rocky soils; drought tolerant; fragrant flowers

▶ ZONE 3

SHRUBS Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Pinus mugo pumilio Mugho pine	Sun	3-5 feet/ 4-6 ft. spread		Adapts to most soils; slow growing and very hardy; newer additions with trademark names such as 'Slo-Grow' or 'Lo-Mound' are also available
Potentilla fruticosa Shrubby cinquefoil	Sun	To 4 feet	May - September	Moist to dry soils; several cultivars available with varying foliage and flower hues; try 'Tangerine' or 'Moonlight'
*Ribes sanguineum** Red-flowering currant	Sun/partial shade	8-12 feet	March - April	Prefers dry soils; drought tolerant; white to deep-red flowers attract hummingbirds; dark-blue to black berries; thornless
*Rosa gymnocarpa** Baldhip rose	Partial shade	To 6 feet	May - July	Dry or moist soils; drought tolerant; small pink to rose flowers

SHRUBS-Evergreen Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Abelia x grandiflora Glossy abelia	Partial Sun/Partial shade	To 8 feet/ 5 foot spread	Summer	Prefers moist, well-drained soils, but drought tolerant; white or faintly pink flowers
Arbutus unedo 'Compacta' Compact strawberry tree	Sun/partial shade	To 10 feet	Fall	Prefers well drained soils; tolerant of poor soils; good in climate extremes; white to greenish-white flowers; striking red-orange fruit
Cistus purpureus Orchid rockrose	Sun	To 4 feet	June - July	Moist to dry well-drained soils; drought resistant; fast growing; reddish purple flowers
Cistus salvifolius White rockrose	Sun	2-3 feet/ 6 ft spread	Late spring	Moist to dry well-drained soils preferred, but can tolerate poor soils; tolerant of windy conditions and drought; white flowers
Escallonia x exoniensis 'fradesii' Pink Princess	Sun/partial sun	5-6 feet	Spring - Fall	Tolerant of varying soils; drought tolerant when established; pink to rose colored flowers; good hedge or border plant; attracts butterflies
Osmanthus delavayi Delavay Osmanthus	Sun/partial shade	4-6 feet	March - May	Tolerant of a broad range of soils; attractive foliage and clusters of white fragrant flowers; slow growing
Osmanthus x burkwoodii Devil wood	Sun/partial shade	4-6 feet	March - April	Drought tolerant once established; masses of small, white fragrant flowers
Rhododendron 'PJM' hybrids	Sun/partial shade	To 4 feet	Mid – late April	Moist to fairly dry soils; well drained organic soil; lavender to pink flowers
Stranvaesia davidiana	Sun	6-20 feet	June	Moist soils; white flowers in clusters; showy red berries
Stranvaesia davidiana undulata	Sun	To 5 feet	June	Moist soils; lower growing irregularly shaped shrub; great screening plant
*Vaccinium ovatum** Evergreen huckleberry	Partial shade/ shade	3-15 feet	March	Moist to slightly dry soils; small pinkish-white flowers; berries in August

▶ ZONE 3

GROUNDCOVER - Evergreen

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Arctostaphylos uva-ursi** Kinnikinnik	Sun/partial shade		April - June	Prefers sandy/rocky, well-drained soils; flowers pinkish-white; bright red berries; slow to establish; plant closely for good results
*Gaultheria shallon** Salal	Partial shade/ shade	3-7 feet	March - June	Dry and moist soils; white or pinkish flowers; reddish-blue to dark-purple fruit
*Fragaria chiloensis** Wild/Coastal strawberry	Sun/partial shade	10 inches	Spring	Sandy well drained soils; flowers white; small hairy strawberries; evergreen; aggressive spreader
Helianthemum nummularium Sunrose	Sun	To 2 feet/ 2 ft. spread	May - July	Prefers well-drained soils, but will tolerate various soils; low-growing, woody sub shrub; many varieties are available with flowers in salmon, pink, red, yellow and golden colors
Lavandula angustifolia Lavender	Sun/partial shade	To 1.5 feet	June - August	Adaptable to various soils; blue, lavender, pink to white flowers, semi-evergreen aromatic perennial
*Mahonia nervosa** Cascade Oregon grape/Dull Oregon grape	Partial shade/ shade	To 2 feet	April – June	Dry to moist soils; drought resistant; evergreen; yellow flowers; blue berries
Mahonia repens Creeping mahonia	Sun/partial shade	3 feet	April - June	Dry to moist soils; drought resistant; yellow flowers; blue berries; native of Eastern Washington
*Penstemon davidsonii** Davidson's penstemon	Sun	To 3 inches	June - August	Low growing evergreen perennial; prefers well-drained soils; drought tolerant; blue to purple flowers

PERENNIALS & ORNAMENTAL GRASSES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Achillea millefolium** Western yarrow	Sun	4 inches – 2.5 feet	June - September	Dry to moist, well-drained soils; white to pink/reddish flowers; many other yarrows are also available
Anaphalis margaritaceae Pearly everlasting	Sun/partial shade	To 18 inches		Drought tolerant perennial; spreads quickly; attracts butterflies
*Bromus carinatus** Native California brome	Sun/partial shade	3-5 feet		Dry to moist soils; tolerates seasonal saturation
Carex buchannii Leather leaf sedge	Sun/partial shade	1-3 feet		Prefers well-drained soils; copper-colored foliage; perennial clumping grass; tolerant of a wide range of soils; inconspicuous flowers
Carex comans 'Frosty curls' New Zealand hair sedge	Sun/partial shade	1-2 feet	June - August	Prefers moist soils; finely textured and light green; compact, clumping perennial grass; drought tolerant when established; inconspicuous flowers

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PERENNIALS & ORNAMENTAL GRASSES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Coreopsis spp.	Sun	1-3 feet		Dry to moist soils; drought tolerant; seeds attract birds; annual and perennial varieties; excellent cut flowers
Echinacea purpurea Purple coneflower	Sun	4-5 feet		Prefers well drained soils; hardy perennial; may need occasional watering in dry months
*Elymus glaucus** Blue wildrye	Sun/partial shade	1.5-5 feet		Dry to moist soils; shade tolerant; rapid developing, but short lived (1-3 years); not good lawn grass
*Dicentra formosa** Pacific bleeding-heart	Sun/shade	6-20 inches	Early spring - early summer	Moist, rich soils; heart-shaped flowers
*Erigeron speciosus** Showy fleabane	Sun/partial shade	To 2 feet	Summer	Moist to dry soils; dark violet or lavender blooms; fibrous roots
Festuca ovina 'Glauca' Blue fescue	Sun/partial shade	To 10 inches	May - June	Prefers moist, well-drained soils; blue-green evergreen grass; drought tolerant; shearing will stimulate new growth
*Festuca idahoensis** Idaho fescue	Sun/partial shade	To 1 foot		Bluish-green bunching perennial grass; drought tolerant
*Fragaria vesca** Wood strawberry	Partial shade	To 10 inches	Late spring - early summer	Dry to moist soils; white flowers
Gaura lindheimeri Gaura	Sun	2.5-4 feet		Perennial; fairly drought tolerant and adaptable to varying soil types; long blooming period
*Geum macrophyllum** Large-leaved avens	Sun/partial shade	To 3 feet	Spring	Moist, well-drained soil; bright yellow flowers; other *Geum* cultivars available, some which may require supplemental watering
Geranium maculatum Spotted geranium	Sun/shade	To 1.5 feet	July	Moist, well-drained soils; low perennial; pale pink, blue to purple flowers
Geranium sanguineum Cranesbill	Sun/partial shade	To 1.5 feet	May - August	Moist soils; deep purple almost crimson flowers
Helichrysum italicum Curry Plant	Sun	To 2 feet	Summer	Moist or dry soils; hardy evergreen perennial; a good companion to lavender; bright yellow flowers; fragrant
Helictotrichon sempervirens Blue oat grass	Sun/partial shade	1-1.5 feet	June - August	Tolerant of a variety of soil types but prefers well-drained soil; clumping bright blue evergreen grass; bluish white flowers
Hemerocallis fulva Day lilies	Sun/partial shade	1-4 feet	Summer	Tolerant of a variety of soil types; easy to grow and tolerant of neglect; hardy perennial; entire plant is edible
Heuchera americana Coral bells (alumroot)	Sun/partial shade	1-2 feet	June - August	Moist to dry, well-drained soils; never wet; easily transplantable perennial; red, greenish-white flowers; may need supplemental watering in dry season
Heuchera micrantha 'Palace purple' (alumroot)	Sun/partial shade	1-2 feet	June - August	Moist, well-drained soils; bronze to purple foliage in shade; small, yellowish-white flowers; perennial, evergreen; a number of other species and varieties are available. Try *H. sanguinea* for bright red flowers
*Lupinus** *spp.* Lupines	Sun	3-5 feet	March - September	Moist to dry soils; various native varieties; blue to purple, violet to white flowers; both native and non-native varieties

PERENNIALS & ORNAMENTAL GRASSES

SPECIES/ COMMON NAME	EXPOSURE	MATURE SIZE	TIME OF BLOOM	COMMENTS
*Lupinus bicolor** Two-color lupine	Sun	4 inches- 1.5 feet	Spring	Dry gravelly soils; small-flowered; annual
*Lupinus latifolius** Broadleaf lupine	Sun	To 1 foot	June - August	Dry to moist soils; perennial; bushy herb; bluish flowers
*Lupinus polyphyllus** Large-leafed lupine	Sun	To 3 feet	Spring - summer	Dry to moist, sandy to gravelly soils; perennial
*Maianthemum dilatatum** False lily-of-the-valley	Partial shade/ shade	3-12 inches	Spring	Prefers moist soils; small, white flowers; light-green to red berries
Pennisetum alopecuroides Fountain grass	Sun/partial shade	1-2 feet	August - September	Moist, well-drained soils; tolerant of many soil types; clump-forming grasses. A number of varieties are available in different heights and bloom times. Try *P. caudatum* (White-flowering fountain grass) and *P. alopecuroides* cultivars 'Hameln' and 'Little Bunny' (Dwarf fountain grass)
Pennisetum orientale Oriental fountain grass	Sun/partial shade	1-3 feet	June - October	Prefers moist, well-drained soils; somewhat drought tolerant; small clumping, blooming grass, showy pink flowers; fountain grasses will benefit from annual shearing in late winter/early spring, but not required
Penstemon fruticosus Shrubby penstemon	Sun	8–10 inches	May	Prefers well-drained soils; evergreen perennial; drought tolerant; violet-blue flowers 1" long attract hummingbirds
*Polystichum munitum** Swordfern	Partial shade/ Deep shade	2-4 feet		Prefers moist, rich soil conditions, but drought tolerant; large evergreen fern
*Potentilla gracilis** Graceful cinquefoil	Sun	1-2 feet	July	Moist to dry soils; yellow flowers
Rudbeckia hirta Black-eyed susan	Sun/partial shade	3-4 feet	Summer	Moist to dry soils; showy flowers, hardy and easy to grow; several other varieties are available
*Smilacina racemosa** False Solomon's seal	Partial sun/shade	1-3 feet	April - May	Moist soils; creamy white flowers; red berries
*Solidago canadensis** Canadian goldenrod	Sun/partial shade	1-2 feet	Late summer - early fall	Dry to moist soils; yellow flowers

Bog Garden Plants

A bog garden presents a unique design option for managing stormwater on site. A lined depression filled with an organic soil mix and wetland vegetation can be an attractive method for promoting evaporation and transpiration of collected runoff. A functioning bog garden generally displays no standing water, but soils are saturated much of the time, necessitating facultative wetland plant selections.

To select plant species appropriate for a bog garden refer to those listed in this appendix, **Zone 1**, as well as those found in the following table. The list below includes additional native and non-native plant species (not listed in the bioretention plant list) that have been successfully applied in Pacific Northwest bog gardens. It may be necessary to provide additional water to the bog system during seasonal dry periods due to a lack of stormwater runoff.

As with any system, plant species in a bog garden setting have various preferences for moisture and sun. Check listed comments below and research plant needs to optimize growth in the conditions specific to individual bog garden systems.

Bog Garden

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Adiantum aleuticum** Western maidenhair fern	Shade/partial shade	1-2 feet		Moist to wet soils; graceful, delicate fern; vivid bright green with black stems; spreads through creeping rhizomes; often called *A. pedatum*, but this refers to the related East Coast maidenhair fern; also try *A. capillis-veneris* (Venus-hair fern)
*Andromeda polifolia** Bog rosemary	Sun/partial shade	1-1.5 feet	Spring	Moist to wet soils; low-growing evergreen shrub; white to pink flower clusters; ornamental varieties include 'Blue Ice', 'Grandiflora' and 'Nana'
*Blechnum spicant** Deer fern	Shade/partial shade	1-3 feet		Moist to wet soils; has both evergreen and deciduous leaves; prefers soils high in organic material; is sensitive to frost
Carex spp. Sedges	Sun/shade	varies		A number sedge choices are great options for a bog garden setting; two are listed in Zone 1 of this appendix, but there are many alternative species to investigate, including *Carex mertensii** (Mertens' sedge) and *C. lyngbyei** (Lyngby's sedge)
*Eleocharis palustris** Creeping spike-rush	Sun	To 3.5 feet		Wet soils to shallow water; perennial forming small clumps
*Empetrum nigrum** Crowberry	Sun	To 8 inches	Early spring	Dry to wet/boggy soils; low-growing evergreen shrub; small purplish flowers and purplish-black berries
*Equisetum hyemale** Scouring-rush	Sun/partial shade	2-5 feet		Moist to wet soils; hollow-stemmed, evergreen perennial; spreads through creeping rhizomes; vigorous and persistent; with high silica content; also *E. scirpoides* (Dwarf horsetail); use both with caution – *Equisetum* can be very invasive and difficult to remove once established
*Gaultheria ovatifolia** Oregon wintergreen/ Western teaberry	Partial shade	To 1 foot	Late spring - summer	Moist to wet soils; low-growing evergreen shrub; pink or whitish flowers and red berries; also *G. humifusa** (Alpine wintergreen)
*Glyceria elata** Tall mannagrass	Sun/partial shade	3-4.5 feet		Moist to wet soils; loosely tufted perennial, spreads through creeping rhizomes; also try the taller *G. grandis** (Reed mannagrass)

Bog Garden

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Gunnera manicata Gunnera	Sun/partial shade	4-6 feet/ 4-8 ft. spread		Moist to wet organic soils; prefers humid setting; non-native from Brazil and Columbia needing mulching protection in the winter; also referred to as 'giant rhubarb'; huge rounded leaves; needs plenty of space; also *G. tinctoria* from Chile
Hakonechloa macra Japanese forest grass	Shade/partial shade	1-3 feet		Prefers moist, rich soil; slowly spreading perennial grass; green leaves turn coppery orange in the fall
Hosta Plantain lily	Shade/partial sun	To 2.5 feet	Summer	Prefer moist, rich soil; many varieties and hybrids available in a various sizes, foliage textures and colors; thin spikes of blue or white flowers; some are tolerant of sun, but most prefer shade
Juncus spp. Rushes	Sun/shade	varies		As with the *Carex* species, there are a number of native rushes that would work well in a bog garden. Three options are listed in Zone 1 of this appendix. Others to investigate include *Juncus mertensianus** (Mertens' rush) and *J. acuminatus** (Tapered rush)
*Kalmia occidentalis** Swamp-laurel	Sun	.5-2 feet	Spring - early summer	Also known as *K. polifolia*, prefers moist soils; low shrub with aromatic leaves; rose-purple flowers; also try *K. microphylla** (Western bog-laurel) a mat-forming, evergreen shrublet; generally found in wet subalpine conditions
*Ledum groenlandicum** Labrador tea	Shade/partial sun	1.5–4.5 feet	Summer	Moist to boggy soils; evergreen shrub with small white flower clusters; foliage aromatic when crushed
Ligularia dentata Bigleaf ligularia	Shade/partial shade	3–5 feet	Summer	Moist to wet soils; large-leaved, clumping perennial; yellow-orange blooms; not tolerant of high heat or low humidity; try *L. dentata* cultivars 'Othello' and 'Desdemona'; also *L. przewalskii* (Shavalski's ligularia) and *L. stenocephala* (Narrow-spiked ligularia)
*Linnaea borealis** Twinflower	Shade/partial shade	4-6 inches	June - September	Moist or dry soils; evergreen perennial; pink, fragrant, trumpet-like flowers; trailing ground cover; try *L. borealis* on the less saturated margins of a bog garden; may be difficult to establish
Lobelia cardinalis Cardinal flower	Sun/partial shade	2-4 feet	Summer	Wet to moist, rich soils; clumping perennial; tubular, bright red, inch-long flowers; also try *L. siphilitica* (Blue lobelia), another perennial with blue flowers
*Lysichiton americanum** Skunk cabbage	Shade/partial shade	2-3 feet	March	Prefers wet soils; deciduous perennial; has odor that some consider to be skunky especially when blooming; yellow hooded fleshy flower spike; great leaves dominate
Matteuccia struthiopteris Ostrich fern	Sun/shade	To 6 feet		Moist, rich soils; hardy northern fern; clumping narrowly at base with foliage spreading to 3 feet in width
Mimulus spp. Monkey-flower	Sun/partial shade	1-3 feet	Spring-summer	Wet soils; perennial or annual that reseeds nicely and keeps spreading; many species available including natives, *M. guttatus** (Yellow monkey-flower) and *M. tilingii** (Mountain monkey-flower); also *M. lewisii** with rose-red to pale-pink flowers

Bog Garden

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Myrica gale** Sweet gale	Sun/partial shade	To 4 feet		Moist to wet soils; aromatic, deciduous perennial shrub; glossy green leaves; a nitrogen fixing species
Oplopanax horridum Devil's club	Shade/partial sun	3-10 feet		Moist to wet soils; forms extensive clumps; aggressive grower, but huge palmate leaves highly decorative; clusters of small whitish flowers; wand-like stems have sharp spines
Osmunda cinnamomea Cinnamon fern	Sun/partial shade	2-5 feet		Moist to wet soils; large deciduous fern; unfolding 'fiddlehead' fronds are edible
*Oxycoccus oxycoccos** Bog cranberry	Sun	4-16 inches		Moist to wet soils, prefers *Sphagnum* moss mats, peat and acidic conditions; evergreen, low-creeping vine-like shrub; pink to red flowers; red berries; shade intolerant
*Polystichum munitum** Sword fern	Shade/partial shade	2-5 feet		Moist soils; large evergreen fern; dark green fronds with dagger shaped leaflets; hardy and easy to grow
*Potentilla palustris** Marsh cinquefoil		To 3 feet		Moist to wet soils; perennial with reddish-purple flowers; stems both prostrate and ascending
*Ribes divaricatum** Wild gooseberry	Partial shade/shade	1.5-6.5 feet		Prefers wet or moist soils; green or purple flowers and smooth, dark purple berries; a hedge or screen provides good habitat for birds and wildlife; beware prickly spines; also try *R. lacustre** (Black gooseberry)
*Salix arctica** Arctic willow	Sun/shade	To 2 feet	Spring	Moist soils; deciduous, prostrate or trailing shrub; leaves are dark green on the bottom and lighter on top; brownish to pink flowers; see Zone 1 of this appendix for details on *S. purpurea* 'Nana'
*Trientalis arctica** Northern starflower	Shade/partial shade	To 8 inches		Wet, boggy soils; small perennial; star-shaped white flowers, or with a pink tinge

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Appendix 4

Bioretention Cell and Bioretention Swale Research: Flow Control and Pollutant Removal Capability

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Davis, A.P., Shokouhian, M., Sharma, H., & Minami, C. (2001 January/February). Laboratory study of biological retention for urban stormwater management. *Water Environment Research, 73*, 5-14.	Laboratory	Two laboratory-scale bioretention boxes were constructed with perforated pipes at 2 different depths to collect effluent. Synthetic stormwater runoff was applied at specific flow rates and durations, and pollutant removal assessed. Soil composition: sandy loam (pH 6.4, CEC 2.9 meq/100 g soil, organic matter content 0.6%) with shredded hardwood bark mulch topcoat. Boxes included creeping juniper plantings.	Pollutant removal: • Copper: 89 to 98%. • Lead and Zinc: > 97 to 98% (lower ports below detectable limits). • Ammonium: -8 to 54% upper ports, 60 to 79% lower ports. • Nitrate: -96% upper port, 24% lower port, (large box only). • Phosphorous: 16 to 73% upper and mid ports, 71 to 81% lower ports.	• High metal removal in upper layers of large and small box. Removal did not increase much with depth. • Significant metal accumulation found in mulch layer samples. • Nutrient removal more variable than metals. Removal increased with depth. • 98 effluent samples taken from upper and lower pipes in the small box and 80 samples from the large box.
Davis, A..P., Shokouhian, M., Sharma, H., Minami, C., & Winogradoff, D. (2003 January/February). Water quality improvement through bioretention: Lead, copper, and zinc removal. *Water Environment Research, 75*, 73-82.	Laboratory and field	Two laboratory-scale bioretention boxes were constructed with perforated pipes at 2 different depths to collect effluent. Synthetic stormwater runoff was applied at varying flow rates, flow durations, metal concentrations, and pH to assess pollutant removal. Soil composition: sandy loam topped with 2.5 cm of mulch. Boxes included creeping juniper plantings. Additionally, synthetic stormwater runoff was applied and effluent measured at 2 field sites with bioretention facilities.	Pollutant removal: Lab • Copper: 87% to 98%. • Lead: 92% to 98%. • Zinc: 85% to 98%. Field Greenbelt facility: • Copper: 97%, lead: 95%, zinc: 95%. Largo facility: • Copper: 43%, lead: 70%, zinc: 64% cadmium: 27%, total phosphorous: 87%, TKN: 67%, nitrate: 15%.	Lab: • Removal for metals was excellent and similar to initial study (see above). • Removal at upper ports was affected slightly by flow rate and duration. • Removal at lower ports was not affected by flow rate and duration. • Removal at upper ports was affected slightly by pH and concentration. • Removal at lower ports was not affected by flow, pH and concentration (soil likely buffering pH changes). Field: • Greenbelt facility showed good agreement with lab analysis. • Largo removal was significantly lower and speculatively attributed to Greenbelt being an older facility with mature groundcover and having a higher fraction of fines in the soil.

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Kim, H., Seagren, E.A., & Davis, A.P. (2003, July/August). Engineered bioretention for removal of nitrate from stormwater runoff. *Water Environment Research, 75*, pp. 355-367.	Laboratory	A laboratory pilot-scale bioretention cell engineered with an anoxic zone at bottom of cell was constructed to assess nitrate removal potential (this phase was part of a larger nitrate removal study). A sand layer mixed with newspaper (electron donor for denitrification process) was placed at bottom of cell and used as a saturated anoxic zone. Synthetic stormwater was applied to the cell and effluent collected after passing through sand layer.	Pollutant removal: • First 2-3 hours no nitrate or nitrite observed in effluent during applications at 7 and 42 days after system inoculation. • After 2-3 hours removal for nitrate and nitrite were 70% to 80% for the 7 to 8-hour stormwater applications.	• No nitrate or nitrate in the effluent for the first 2 to 3 hours likely attributed to the following: The amount of effluent released during that period was water stored in system from previous application; accordingly, that water had a longer period exposed to the anoxic zone favorable to denitrification. • Pilot-scale bioretention cell performance suggests that incorporating an anoxic zone in the bottom of bioretention area can be effective for removing nitrate.
Horner, R., Lim, H., & Burges, S.J. (2002, November). *Hydrologic monitoring of the Seattle Ultra-Urban stormwater management projects* (Water Resources Series Technical Report No. 170). Seattle, WA: University of Washington.	Field	660 feet of residential road was narrowed and linear bioretention/ bioswales were installed within the right-of-way. A v-notch weir installed at the ultimate outfall of the project measured surface flow volumes and timing. Flows for the conventional pre-construction street were compared to the retrofit design.	Pre-construction (March-July 2000): • Rainfall: 7.96 inches. • Runoff: 4979 cubic feet. Post construction (March-July 2001): • Rainfall: 9.00 inches. • Runoff: 132 cubic feet. Oct 20 2003 record storm event: • Rainfall: 4.22 inches (32.5 hour storm duration). • Runoff: none.	• Approximately 97% reduction in surface flow volume was recorded from pre- to post-construction conditions. • Contributing area is approximately 2.3 acres and total impervious area is approximately 35%. Total rooftop contribution reaching the streets, swales and monitoring station is not known.

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Hon G. E., Seagren, E., Davis, A. P. (2002, June). Sustainable Oil and Grease Removal from Stormwater Runoff Hotspots using Bioretention. Paper for the 74th *Annual Conference and Exhibition of the Pennsylvania Water Environment Association.* State College, PA.	Laboratory	The research examined the capacity of a mulch layer to capture oil and grease (O&G) via sorption and filtration. Simulated stormwater runoff carrying selected hydrocarbons was applied to a bench-scale "reactor" with a 3-cm thick leaf compost layer. Stormwater was applied at a rate of 4 cm/hr for 6 hours resulting in a naphthalene concentration of 1.7-2.4 mg/L. To distinguish biodegradation and other removal pathways, experiments with and without microbe populations were conducted. Mulch samples were analyzed for contaminants, volatilized hydrocarbons captured, and microbial population counts conducted to correlate with biodegradation rates.	During simulated storm event: • Approximately 90% removal of dissolved naphthalene from aqueous phase via sorption. After storm event (37 and 40 hours): • Abiotic experiment: approximately 32% removal via biodegradation in the mulch layer. • Biotic experiment: approximately 72% removal via biodegradation in the mulch layer. After storm event (74 hours): • Biotic experiment: approximately 95% removal via biodegradation in the mulch layer. Losses due to volatilization were negligible.	• Naphthalene, in dissolved and particulate-associated phases, was selected because of its toxicity and common presence in stormwater. • Research was designed to test bioretention in automotive-intensive hotspots such as gas stations. • The native microbial population in the mulch was capable of biodegradation and inoculation with specific microorganisms to degrade O&G was not necessary. • The change in microbial numbers corresponded to the loss of naphthalene (i.e., microbial numbers were highest when the most naphthalene was degraded).

Appendix 5

Phytoremediation

The presence of vegetation can have various effects on contaminants in soil or water. Studies indicate that vegetated soils are capable of more effective degradation, removal, and mineralization of total petroleum hydrocarbons (TPHs), polycyclic aromatic hydrocarbons (PAHs), pesticides, chlorinated solvents, and surfactants than are nonvegetated soils (US EPA, 2000). Certain plant roots can absorb or immobilize metal pollutants including cadmium, copper, nickel, zinc, lead, and chromium, while other plant species are capable of metabolizing or accumulating organic and nutrient contaminants. An intricate and complex set of relationships and interactions between plants, microbes, soils, and contaminants make these various phytoremediation processes possible.

The term phytoremediation is a combination of the Greek prefix *phyto*, for plant, and the Latin root *remidium*, "to correct or remove an evil". Defined, phytoremediation is the utilization of vascular plants, algae, and fungi to control, break down, or remove wastes, or to encourage degradation of contaminants in the rhizosphere, or root region of the plant (McCutcheon & Schnoor, 2003). Phytoremediation processes are most effective where contaminants are present at low to medium levels, as high contaminant levels can inhibit plant and microbial growth and activity (US EPA, 2000).

Metals, organics, and inorganic contaminants in stormwater and soils can be subject to:

- Degradation.
- Extraction by the plant.
- Containment within the plant.
- A combination of these mechanisms.

Plant processes that promote the removal of contaminants from soil and water are either direct or indirect. Direct processes include plant uptake into roots or shoots and transformation, storage, or transpiration of the contaminant (Hutchinson et al., 2003). Indirect plant processing involves the degradation of contaminants by microbial, soil, and root interactions within the rhizosphere (Hutchinson).

1. Degradation *(rhizodegradation, phytodegradation, phytovolatilization)*

Table 1 Phytoremediation processes contributing to degradation or transformation of contaminants in soil and water.

Type	Process	Appropriate contaminants
Rhizodegradation (Plant-assisted bioremediation, phytostimulation)	Plant exudates and other processes enhance soil bacterial growth, spur degradation by mycorrhizal fungi and microbes, and add aeration channels and oxygen to soils	Petroleum hydrocarbons, BTEX, PAHs, PCP, perchlorate, pesticides, PCBs and other organic compounds
Phytodegradation	Aquatic and terrestrial plants take up, store and biochemically degrade or transform organic compounds	Chlorinated solvents, methyl bromide, atrazine, DDT, tetrabromoethene, tetrachloroethane, dichloroethene, Cl-and P-based pesticides, PCBs, phenols, anilines, nitriles, nutrients
Phytovolatilization	Plants take up volatile metals and organic compounds and transpire or diffuse contaminant or modified form of contaminant out of roots, leaves or stems	Arsenic, tritium, Se, mercury, m-xylene, chlororbenzene, tetrachloromethane, trichloromethane, trichloroethane, and other chlorinated solvents

(Adapted from information in US EPA, 2000)

The rhizosphere, or area of soil 1 mm from the plant root, is a dynamic and intricately complex environment (Olson et al., 2003). Increased microbial activity and biomass in this area of plant-microbe interaction has become recognized as the "rhizosphere effect" and is critical for rhizosphere bioremediation to take place (Olson et al.). Plant roots exude enzymes and other organic substances. These releases dramatically enhance microbial numbers and metabolic activity, and increase contaminant degradation and the availability of substances for uptake by the roots (Christensen-Kirsh, 1996). The process of breaking down an organic contaminant in soils through active microbial behavior enhanced by the rhizosphere is known as *rhizodegradation* (McCutcheon & Schnoor, 2003).

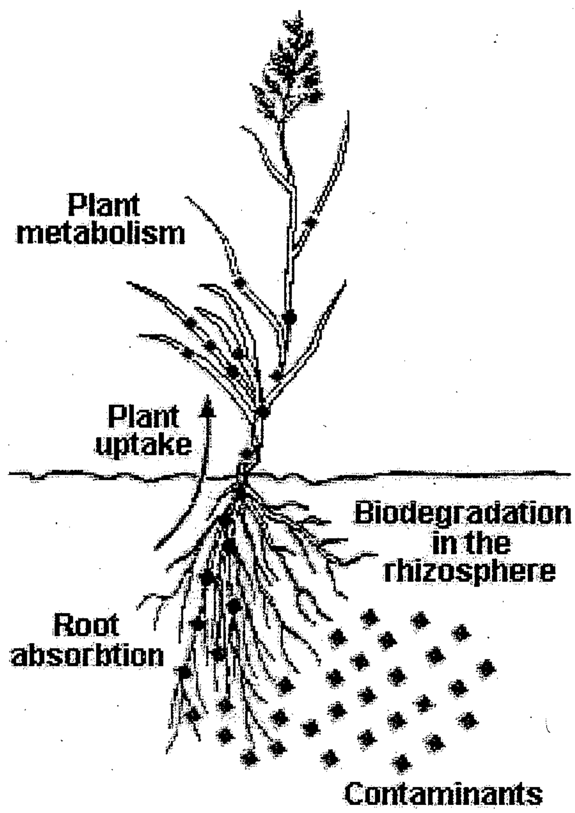

Figure 1 Illustration of basic phytoremediation pathways

The amount and type of compounds released into the soil, and the rhizosphere impacts on associated microbial communities, are specific to plant species (Olson et al., 2003). A synergistic relationship that promotes the exchange of water and nutrients is often established between plant roots and specialized soil fungi or mycorrhizae. This relationship also enhances plant growth (Banks et al., 2000).

Though plants are generally not capable of actually taking in and utilizing highly absorbed contaminants, such as PAHs, the presence of vegetation has been shown to accelerate the degradation of hydrocarbons by enhancing microbial activity (Banks et al., 2000). Root systems can encourage microbial degradation of large molecular organic contaminants (such as PAHs) that tend to bind to soil particles by activating otherwise dormant areas in the soil (Hutchinson et al., 2003). In some instances, the exuded enzymes are capable of detoxifying organic compounds without microbial assistance, a process known as *phytodegradation* (McCutcheon & Schnoor, 2003).

Plants transform certain contaminants through oxidation and reduction reactions, a conjugation phase (foreign compound joined by a plant sugar amino acid, thisol, or glutathione molecule), and deposition of the conjugates into vacuoles and cell walls (Dzantor & Beauchamp, 2002; Subramanian & Shanks, 2003).

The availability of a contaminant for uptake and transformation is also dependant upon the age of the contaminant and certainly the plant species (US EPA, 2000). This process of breaking down contaminants by plant metabolic activity is referred to as phytodegradation or *phytotransformation;* these terms can also apply to the breakdown of contaminants outside the plant through the release of enzymes produced by the plant and which result in the transformation of the compound (US EPA, 2000).

2. Extraction *(phytoextraction/phytomining, rhizofiltration, phytovolatilization)*

Table 2 Processes involving plant uptake or extraction of contaminants from soils or water.

Type	Process	Appropriate Contaminants
Phytoextraction (Phytomining)	Chemicals taken up with water by vegetation; harvested shoots could be smelted or metals otherwise extracted	Metals, metalloids, radionuclides, perchlorate, BTEX, PCP, organic chemicals not tightly bound to soil particles
Rhizofiltration	Contaminants taken up, sorbed, or precipitated by roots and/or shoots; sorbed to fungi, algae and bacteria	Metals, radionuclides, organic chemicals, nitrate, ammonium, phosphate, and pathogens
Phytovolatilization	Plants take up volatile metals and organic compounds and transpire or diffuse out of roots, leaves or stems	Se, tritium, As, Hg, m-xylene, chlororbenzene, tetrachloromethane, trichloromethane, trichloroethane, and other chlorinated solvents

(Adapted from information in US EPA, 2000)

Depending on the plant type and the contaminant, direct uptake can be considered either a passive and/or an active process (Chiou, 2002). The principal process is passive transport, with the primary transport medium, external water and soil water, carrying the contaminant into the plant. Active transport requires the plant to expend energy and generally applies to nutrients and other organic and inorganic ions required and extracted by the plant (Chiou).

Plants actually need metals, such as zinc and copper, as well as nutrients, to grow. When soil surrounding plant roots is deficient in essential elements, plants will exhibit symptoms indicative of deficiency (loss of leaf color, withering, dead spots, etc.) (Stern, 2000). Some plants, however, referred to as hyperaccumulators, make no distinction between heavy metals (such as cadmium or selenium) and those metals nutritionally necessary for growth (Raskin & Ensley, 2000; Stern). These plants absorb the metals through the root structure and store them in cell vacuoles, where tissues have been measured to contain 1,000 to 10,000 ppm of various heavy metals (Stern).

Potentially hazardous metals present in stormwater, such as zinc, copper, cadmium, and lead, can be absorbed by both terrestrial and aquatic plant roots as well as the shoots of submersed plants (Fritoff & Greger, 2003). The retention time and interactions with other elements in the water affect the bioavailablity of metals within a vegetated system exposed to stormwater (Fritoff & Greger). Metals may be contained by physical sequestration or accumulation in roots of non-harvestable plants.

The most important component of extractive phytoremediation is the availability of the compound (Dzantor & Beauchamp, 2002). The lipophilicity (fat-solubility), or distribution of a chemical from the soil solution to the lipids in the plant cell, is the primary controlling factor in the ability of plants to absorb and translocate organic chemicals (Hutchinson et al., 2003). Once transported into the plant cells, the chemical can be metabolized in a process very similar to mammalian metabolism; thus plants utilizing this process are frequently referred to as "green livers" (Dzantor & Beauchamp).

Using a process called *phytovolatilization,* elemental contaminants can be taken up, transformed to a volatile form, and transpired through roots, stems, or leaves (Doucette, Bugbee, Smith, Pajak, & Ginn, 2003). Selenium, for example, can be transformed into volatile dimethyl selenide, not known to represent any health risk once transported through air. Volatile organic compounds can be taken up and directly transpired or diffused through roots, stems, and foliage (Doucette et al.). Application or use of phytovolatilization requires a thorough examination of potential health risks associated with air transport of the contaminant or modified form of the contaminant in the atmosphere.

3. Containment/Immobilization *(phytostabilization, rhizofiltration)*

Table 3 Immobilization or containment processes preventing contaminant movement, leaching or transport.

Type	Process	Appropriate Contaminants
Phytostabilization	Vegetation prevents erosion and sorbed contaminant transport; often involves revegetating an area where natural vegetation cannot be sustained due to high contaminant concentrations	Metals, phenols, tetrachloromethane, trichloromethane, and other chlorinated solvents
Rhizofiltration	Contaminants taken up, sorbed, or precipitated by roots and/or shoots; sorbed to fungi, algae and bacteria	Metals, radionuclides, organic chemicals, nitrate, ammonium, phosphate, and pathogens

(Adapted from information in US EPA, 2000)

Root and microbial interactions can immobilize organic and some inorganic contaminants by binding them to soil particles and, as a result, reduce migration of the contaminant to groundwater (Christensen-Kirsh, 1996). The process of holding contaminated soils in place with vegetation, minimizing disturbance of contaminants bound to soil particles, and preventing contaminant movement is referred to as **phytostabilization** (McCutcheon & Schnoor, 2003).

The process where heavy metal contaminants in water are absorbed or precipitated onto or into plant roots is referred to as **rhizofiltration**. The plant may or may not actually take in and translocate the contaminant. The contaminant can be contained, immobilized or accumulated within or on the root structure. Generally this application is associated with contaminants carried in water rather than contaminated soil particles (US EPA, 2000). This process is heavily dependant on pH levels of the solution and harvesting of plants used in this process will often be necessary to reduce the reintroduction of the contaminant into soils or water.

Plant Selection Considerations

Use of native plant species for phytoremediation is generally favored; natives require less maintenance and present fewer environmental and human risks than do non-native or genetically altered species. Non-native species that require fertilizers or large amounts of irrigation will contribute to, rather than reduce, negative effects of stormwater runoff. Properly selected native plant communities are most tolerant of soils, climatic conditions, and seasonal cycles of inundation and drought. However, particular non-native plants may work best in remediation of a specific contaminant and can be safely used under circumstances where the possibility of invasive behavior has been eliminated (US EPA, 2000).

Scientific studies using phytoremediation techniques have focused almost entirely on monoculture trials, while ecosystem and plant community uses and effects remain largely unexplored. The drawbacks of phytoremediation efforts relying on monocultures are increased susceptibility to disease and other natural events damaging the plants, as well as reduced ecological diversity and wildlife habitat benefits (Marmiroli & McCutcheon, 2003).

Limiting Conditions

The primary factors that limit the effectiveness of phytoremediation are climate conditions, particularly temperature, and contaminant exposure to the plant root zone. In temperate regions, dormant periods for many plants that coincide with high precipitation periods may limit contaminant uptake during periods when pollutant loads are potentially largest (Christensen-Kirsh, 1996). Effective phytoremediation requires that root systems extend into the contaminated region or that the contaminants be brought within range of the rhizosphere (US EPA, 2000).

Microbial populations and their level of activity are strongly influenced by soil pH levels and water availability. Most biological activity occurs in soils with pH levels between 5 and 10 (Hutchinson et al., 2003). Low pH levels are optimal for metal availability, but can have adverse effects on vegetation. Microbial activity is maximized when 60 percent of soil pore space is filled with water. Activity is nearly absent with low water availability. Saturated soils have limited available oxygen, forcing a decline in microbial activity (Hutchinson et al.).

The physical characteristics of soil, such as percentages of clay and/or sand, can alter the availability of oxygen, nutrients, and water for plant and microbial use. Soils with high clay content, for example, have lower hydraulic conductivity and diffusion coefficients, and can render contaminants unavailable to microorganisms. The presence of vegetation can promote the development of soil structure, increase microbial activity within the rhizosphere, and, as a result, enhance the transport of water, nutrients, and contaminants through the soils system (Hutchinson et al., 2003). Adding organic amendments, such as compost, to disturbed urban soils can increase plant root growth, improve water-holding capacity of the soil, and encourage a wide variety of soil organisms.

The importance of optimizing the productivity and interactions between plants and microbes cannot be overstated, and the success of most phytoremediation applications (volatilization, extraction, stabilization, transformation, phytodegradation and rhizodegradation) will be largely dependant on this dynamic relationship (Olson et al., 2003).

Phytoremediation efforts can also be influenced by the presence of multiple contaminants, which, in combination, can inhibit pollutant processing. Understanding which contaminants are present is necessary to inform decisions regarding appropriate plant and soil selection (Dzantor & Beauchamp, 2002).

Concerns and Considerations

Utilization of some phytoremediation techniques, such as the extraction and sequestration of heavy metals in plant tissues, may require harvesting and proper disposal or recycling of contaminated vegetation. Most phytoremediative plants, however, do not accumulate significant levels of contamination and do not require specific treatment or disposal (US EPA, 2000). Existing natural vegetation on sites receiving stormwater runoff likely extract, metabolize, and/or degrade many contaminants (US EPA, 2000). However, the complexity of interactions between variables, such as plant communities, climatic conditions, soils, and combinations of contaminants will undoubtedly prohibit a comprehensive understanding of all interactions at every site for some time to come.

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Appendix 6

Sampling of Plant Species Studied for Phytoremediation

The following is a sampling of plant species that have been studied for phytoremediation. Some plants on this list may not be well suited for growing conditions in Puget Sound. A number of plants with identified phytoremediative abilities have not been included on this list because they are an invasive or potentially invasive weed in Washington state. These plants include such species as:

Amorpha fruticosa	(Indigo bush)	Accumulates lead
Azolla pinnata	(Water velvet)	Biosorbs metals
Bacopa monnieri	(Water hyssop)	Accumulates metals
Hydrilla verticillata	(Hydrilla)	Hyperaccumulates metals
Myriophyllum aquaticum	(Parrot feather)	Transforms and degrades a variety of contaminants
Phragmites australis	(Common reed)	Used in reed bed treatment systems (native genotypes do exist that are not considered invasive)

Related native species may not react to contaminants in the same manner as those specified. Different cultivars of the same species and various species of the same genus may differ in reactions and responses to climatic factors (McCutcheon, 2003).

GRASSES/LEGUMES

Species/Common Name	Contaminant	Process	Comments
Agropyron smithii Western wheat grass	Hydrocarbons	Rhizodegradation	Perennial grass used in pastures/lawns; shown in studies to enhance degradation of TPH and PAHs in soils (McCutcheon & Schnoor, 2003).
Agrostis castellana Colonial bentgrass	Metals	Hyperaccumulation	Perennial *A. castellana* has been shown to accumulate As, Pb, Zn, Mn and Al.
Bouteloua gracilis Blue gamma grass	Hydrocarbons	Rhizodegradation	Used for low-water use lawn and pasture grass. Has shown promise in grass mixes to enhance degradation of PAHs in soils (McCutcheon & Schnoor, 2003).
Buchloe dactyloides Buffalo grass	Hydrocarbons	Rhizodegradation/ Accumulation	Perennial grass; low maintenance, drought tolerant lawn requiring little/no mowing. In studies has been shown to reduce TPH and PAHs in soil (McCutcheon & Schnoor, 2003).
Cerastium arvense Field chickweed	Cadmium	Uptake/ Accumulation	Tufted perennial, white flowers. A Northwest (NW) native, a recent study on Vashon Island indicated uptake of cadmium (Institute for Environmental Research and Education, 2003). Additional chickweed varieties found in the NW include *C. beringianum* (Bering chickweed) and *C. fischerianum* (Fisher's chickweed).
Claytonia perfoliata Miner's lettuce	Cadmium	Uptake/ Accumulation	A somewhat succulent annual with white or pink flowers. Also known as *Montia perfoliata*. A smaller attractive variety is *Montia spathulata*. A recent study on Vashon Island indicated uptake and accumulation of cadmium (Institute for Environmental Research and Education, 2003).
Cynodon dactylon Bermuda grass	Hydrocarbons	Rhizodegradation/ Accumulation	Lawn grass; minimum maintenance but needs mowing and can be invasive. In studies where mixed with other grasses, it has reduced TPH and PAHs in soils (McCutcheon & Schnoor, 2003).

GRASSES/LEGUMES

Species/Common Name	Contaminant	Process	Comments
Elymus Canadensis Canadian wild rye	Hydrocarbons	Rhizodegradation/ Accumulation	In combination with other grasses, was shown to reduce PAHs in soils (McCutcheon & Schnoor, 2003). *E. mollis* is a NW native wild rye.
Festuca arundinacea Tall fescue	Pyrene, PAHs	Rhizodegradation/ Phytoextraction	Introduced perennial grass common in the NW; studies have shown enhanced degradation of recalcitrant PAHs (McCutcheon, 2003). Also helpful in uptake of nutrients: nitrogen, phosphorus and potassium (Christensen-Kirsh, 1996).
Festuca rubra Red fescue	Hydrocarbons	Rhizodegradation	Perennial grass often used in lawn mixes; Studies have shown enhanced degradation of TPH and PAHs (McCutcheon & Schnoor, 2003).
Lolium perenne English ryegrass	Hydrocarbons/ Nutrients	Rhizodegradation/ Uptake	Perennial grass shown to uptake nutrients and to significantly enhance degradation of TPH and PAHs in soils (McCutcheon & Schnoor, 2003).
Lupinus albus White lupin	Arsenic	Rhizoaccumulation	A nitrogen fixing legume capable of growth in acidic soils with low nutrient availability. A recent study indicated an ability to take up arsenic, primarily stored in the root structure (Esteban, Vazquez & Carpena, 2003). A number of lupine varieties are native to the NW, including: *Lupinus arcticus* (Artic lupine), *L. littoralis* (Seashore lupin), *L. nootkatensis* (Nootka lupine), and *L. polyphyllus* (Large-leaved lupine).
Lotus corniculatus Birds-foot trefoil	Hydrocarbons	Rhizodegradation/ Accumulation	An introduced European annual herb; when mixed with grasses was shown to reduce TPH and PAHs in soils (McCutcheon & Schnoor, 2003). This plant is generally not recommended for introduction into constructed wetlands of the Puget Sound region (Azous & Horner, 2001).
Melilotus officinalis Yellow sweet clover	Hyrdocarbons	Rhizodegradation	Tall, sweet smelling annual; *M. alba* is more common in NW region. When mixed with other grasses was shown to degrade TPH in soils (McCutcheon & Schnoor, 2003). Also helpful in uptake of nutrients: nitrogen, phosphorus and potassium (Christensen-Kirsh, 1996).
Panicum virgatum Switch grass	Hydrocarbons	Rhizodegradation	Enhances degradation of PAHs in soils (McCutcheon & Schnoor, 2003). *P. occidentale* is a species found in the NW.
Stellaria calycantha Northern starwort	Cadmium	Uptake/ Accumulation	Low sprawling perennial. A number of varieties are common in the NW, including, *S. longifolia* (Long-leaved starwort) and *S. longipes* (Long-stalked starwort). A recent study on Vashon Island indicated uptake and accumulation of cadmium (Institute for Environmental Research and Education, 2003).
Stenotaphrum secundatum St. Augustine grass	Hydrocarbons	Rhizodegradation	Perennial grass often used in lawns; coarse-textured. Decreases TPH and PAHs in soils (McCutcheon & Schnoor, 2003).
Trifolium pratense Red clover	Hydrocarbons	Rhizodegradation	Introduced perennial herb common in the NW. When mixed with other grasses was shown to degrade TPH in soils (McCutcheon & Schnoor, 2003).
Trifolium repens White clover	Hydrocarbons PCBs	Rhizodegradation/ Metablolization	Introduced perennial herb, deep rooting; enhances microbial activity and degradation of PAHs. Nitrogen fixer, and PCB metabolizer.
Vicia spp. Vetch	Nutrients/ Metals	Uptake	Perennial herb, takes up nutrients (nitrogen, phosphorus and potassium); *V. faba* has been shown to accumulate Al (McCutcheon & Schnoor, 2003).

OTHER FORBES

Species/Common Name	Contaminant	Process	Comments
Achillea millefolium Yarrow	Cadmium	Uptake/ Accumulation	Perennial aromatic herb native to the NW. Also known as *A. borealis.* A recent study on Vashon Island indicated uptake and accumulation of cadmium (Institute for Environmental Research and Education, 2003).
Allium schoenoprasum Chives	Cadmium	Hyperaccumulation	Perennial onion relative. A recent agricultural study in Israel indicated Cd was accumulated in roots and leaves (Khadka, Vonshak, Dudai & Golan-Goldhirsh, 2003).
Atriplex hortensis Garden Orach	PCBs	Metabolism	Of the spinach family, Orache is an extremely variable species; *A. patula* (Spearscale), *A. subspicata* and *A. patula* common in the NW. Shows promise transforming PAH and Graden Orach metabolizes PCBs (McCutcheon & Schnoor).
Brassica juncea Indian mustard	metals	Rhizofiltration/ Hyperaccumulation	Various species applicable for removing heavy metals (Pb, Zn, Ni, Cu, Cr, Cd and Ur) from soil or water (McCutcheon & Schnoor, 2003); B. campestris (also known as *B. rapa*) and *B. camestris* are common annual herb species in the NW.
Brassica rapa Field mustard	Cadmium, Zinc	Hyperaccumulation	Known to accumulate metals.
Digitalis purpurea Common Foxglove	Cadmium	Phytoextraction	A recent study on Vashon Island indicated uptake of cadmium; *D. lanata* (Grecian foxglove) shown to transform digitoxigenin (McCutcheon & Schnoor, 2003).
Helianthus annuus Sunflower	Metals PAHs	Extraction/ Metabolism Rhizodegradation	The common sunflower has been the subject of numerous studies and is used to extract heavy metals (Pb, Ur, Sr, Cs, Cr, Cd, Cu, Mn, Ni and Zn). Has shown promise in degrading PAHs in soil (McCutcheon & Schnoor, 2003).
Pteris vittata Brake fern	Arsenic	Hyperaccumulation	P. vittata accumulates arsenic in its above ground shoots (Caille et al., 2003).
Senecia glaucus	Crude Oil	Rhizodegradation	Observed to rhizodegrade crude oil in Kuwait; *Senecio triangularis* (Arrow-leaved groundsel), *S. pseudoarnica* (Beach groundsel), and *S. intergerrimus* (Western groundsel) are among the related perennial herbs in the NW.
Solidago hispida Hairy golden rod	Metals	Hyperaccumulation	Shown to accumulate Al. *Solidago* species shows promise for metabolizing TCE (McCutcheon & Schnoor, 2003). Related NW species include S. Canadensis(Canada goldenrod) and *S. multiradiata* (Northern goldenrod).
Thlaspi caerulescens Alpine pennycress	Cadmium, Zinc, Nickel	Hyperaccumulation	This plant is well recognized for its ability to hyperaccumulate metals. *T. arvense* (Field pennycress) is a common NW annual weed.

TREES, SHRUBS and VINES

Species/Common Name	Contaminant	Process	Comments
Acer rubrum Red maple	Leachate	Uptake	Fairly fast growing deciduous trees that have been utilized to uptake landfill leachate along with hybrid poplars (McCutcheon & Schnoor, 2003). NW species include *A. macrophyllum* (Oregon maple), *A. circinatum* (Vine maple), and *A. glabrum* (Rocky mountain maple).
Betula pendula European white birch	PAHs PCBs	Phytodegradation	Attractive European native, has been shown in laboratory tests to degrade PAHs and PCBs in solution (McCutcheon & Schnoor, 2003).
Gleditsia triacanthos Honey locust	Lead	Phytoextraction	Common honey locust (many cultivars available) has shown promise in the extraction and accumulation of lead (Gawronski, 2003).
Ilex spp. Holly	Cadmium	Accumulation	Evergreen shrub or tree. Recently shown to take up and accumulate cadmium (Institute for Environmental Research and Education, 2003).
Liquidambar styraciflua American sweet gum	Perchlorate	Phytodegradation/ Rhizodegradation	A native of the eastern U.S., grows to 60 ft., and is tolerant of damp soils. Has shown promise for phytoremediation of perchlorate (McCutcheon & Schnoor, 2003).
Maclura pomifera Osage orange	PCBs	Rhizodegradation	A deciduous tree that can withstand heat, cold, wind, drought, and poor soil. Roots have been shown to stimulate PCB-degrading bacteria in the soil (McCutcheon & Schnoor, 2003).
Morus rubra Mulberry	PAHs PCBs	Rhizodegradation	The mulberry is one of a few trees producing phenolic compounds stimulating PCB-degrading bacteria, and thus enhance the degradation of this pollutant. Mulberry has also been shown in the lab to degrade PAHs (McCutcheon & Schnoor, 2003).
Populus spp. Poplars	Chlorinated solvents, PAHs, atrazine, DDT, carbon tetrachloride	Phytodegradation/ Phytovolatilization Phytoextraction	Deciduous trees known for deep rooting and rapid growth. The focus of major attention in the field of phytoremediation, hybrids and clones have been developed for very fast growth and colonization. Poplars can absorb nutrients, such as nitrogen, at a high rate and are used in treatment of land applications of wastewater (McCutcheon & Schnoor, 2003). Known to take up and transform TCE from groundwater (McCutcheon & Schnoor, 2003). Varieties tested include *P. deltoids* (Eastern cottonwood), *P. trichocarpa* (Black cottonwood), *P. simonii* (Chinese poplar) and *P. nigra* (Lombardy poplar). *P. trichocarpa* is a NW native.
Populus tremula Aspen	Pb	Extraction	*P. tremula*, *P. treumloides* (Trembling aspen), and hybrids have shown potential to remediate contaminated water, either from the soil or water table, esp. the extraction of lead (McCutcheon & Schnoor, 2003).
Rosa spp. Paul's scarlet rose	Organic contaminants	Phytodegradation	Paul's scarlet rose is a red, natural climbing rose that can metabolize tetrachlorinated PCB 77. There are, of course many varieties. *R. gymnocarpa* (Dwarf rose) and *R. nutkana* (Nootka rose) are two Washington natives.

TREES, SHRUBS and VINES

Species/Common Name	Contaminant	Process	Comments
Salix spp. Willow	Perchlorate	Phytodegradation/ Rhizodegradation Phytoextraction	Deciduous trees or shrubs needing plenty of water. *S. caroliniana* (Coastal plain willow) and *S. nigra* (Black willow) shown to uptake and degrade percholate in soils as well as phytoextract metals (Cd, Zn and Cu). Additional *Salix* ssp. and hybrids have extracted metals (Cr, Hg, Se and Zn) (McCutcheon & Schnoor, 2003). Species in the NW include, *S. commutata* (Undergreen willow), *S. lucida* (Pacific willow), and *S. sitchensis* (Sitka willow). A study on Vashon Island indicated uptake/accumulation of cadmium by *S. scouleriana* (Scouler's willow) (Institute of Env. Research & Ed., 2003).
Viola spp. Violets	Metals	Phytoextraction/ Hyperaccumulation	Perennial flowering plants with many varieties. *Hybanthus floribundus* (Shrub violet) from Australia, has been found to accumulate high concentrations of metals. A study on Vashon Island, WA found violets growing naturally to have accumulated cadmium (Institute for Environmental Research and Education, 2003). The many varieties in the NW include: *V. adunca* (Early blue violet), *V. langsdorfii* (Alaskan violet), *V. palustris* (Marsh violet), and *V. glabella* (Yellow wood violet).

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Appendix 7 Permeable Paving Research: Infiltration Performance Over Time and Maintenance Strategies

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Porous Asphalt				
Fwa, T.F., Tan, S.A., & Guwe, Y.K. (1999). Laboratory evaluation of clogging potential of porous asphalt mixtures (Paper No. 99-0087). In *Transportation Research Record: Journal of the Transportation Research Board.* No. 1681, pp. 43-49.	Laboratory	Soil was washed into four different porous asphalt mixtures. Permeability (K) was measured after each clogging attempt until the change in permeability was negligible.	Mix 1: initial K = 300.88 in/hr terminal K = 22.00 in/hr Mix 2: initial K = 820.22 in/hr terminal K = 457.20 in/hr	Analysis utilized falling head test that increases infiltration rates; however, rates for optimum mixes far exceed any design storm infiltration need. All mixes currently used on Singapore roadways are apparently used as a topcoat application.
Wei, I.W. (1986). *Installation and evaluation of permeable pavement at Walden Pond State Reservation – Final report.* Report to the Commonwealth of Massachusetts, Division of Water Pollution Control (Research Project 77-12 & 80-22). Boston, MA: Northeastern University, Department of Civil Engineering.	Field evaluation of Walden Pond State Park parking lot in Massachusetts.	Various asphalt mixes were installed in different locations in the new parking lot and evaluated for infiltration rates using sprinkler systems and collection wells.	Best performing mixes: 1978 / 1980 / 1981 K mix: 40 in/hr 38 in/hr 37 in/hr J3 mix: 28 in/hr 4 in/hr 13 in/hr	Test plots were exposed to traffic, but not the heaviest loads in the overall parking area. No maintenance program.
St. John, M.S., & Horner, R.R. (1997). *Effect of road shoulder treatments on highway runoff quality and quantity.* Seattle, WA: Washington State Transportation Center (TRAC).	Field evaluation of road shoulder treatments in Washington state.	Three types of road shoulder treatments (conventional asphalt, gravel, and porous asphalt) were installed on a heavily traveled two-lane road. Flow-weighted composite samples were collected and runoff quality and quantity was evaluated.	After one year of use the porous asphalt shoulders showed no signs of clogging and had an average infiltration rate of 1750 in/hr.	During the year of monitoring approximately 4.2 ft^3 of sand was applied per test section length for routine sanding operations. No maintenance program reported for the porous asphalt shoulders.
Cahill, Thomas, Cahill Associates. Personal communication, April, 2003.	Interview Tom Cahill concerning their porous asphalt installations.	Cahill Associates has installed approximately 80 porous asphalt surfaces (mostly parking lots and recreation facilities) over the past 20 years. Visual inspections are conducted during rain events.	Visual inspections indicate no failures of any installations and Cahill estimates that oldest surfaces are functioning at 80% of initial capacity.	Cahill stresses that proper installation and strict sediment control are critical. Cahill installations use a perimeter infiltration gallery (hydrologically connected to storage under paved surface) as a backup if asphalt infiltration rate is degraded.
Hossain, M., Scofield, L.A., & Meier, W.R. (1992). Porous pavement for control of highway runoff in Arizona: Performance to date. In *Transportation Research Record No. 1354,* Transportation Research Board, National Research Council, Washington, D.C., pp. 45-54.	Field evaluation near Phoenix, Arizona.	Structural integrity and permeability were evaluated for a 3,500 ft-long porous pavement test section installed on the three northbound lanes of Arizona State Route 87 near Phoenix.	• Initial permeability (1986): 100 in/hr. • After 5 years of service (1990): 28 in/hr.	The porous asphalt has performed well in a heavy traffic (highway) application with "no cracking or significant surface deformation having occurred during the 5 years of service."

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Permeable Pavers				
Borgwardt, S. (1994). *Expert Opinion.* Hannover, Germany: University of Hannover, Institute for Planning Green Spaces and for Landscape Architecture.	Field evaluation of two train station parking lots in Europe. One lot was two years old and the other five years old.	Sprinklers applied simulated rainfall on test section and measured infiltration utilizing infiltrometer (double ring method). Infiltration rates at 60 minutes are used to represent saturated conditions. Grain size distribution was evaluated to correlate paver design with infiltration rate.	• 2-yr old lot: infiltration rate = 2.84 in/hr after 60-min sprinkling. • 5-yr old lot: infiltration rate = 5.70 in/hr after 60-min. of sprinkling.	Higher infiltration rate for the older as compared to the newer installation likely due to application of sand on top of gravel in drainage openings and fines introduced from inadequately washed aggregate base material in newer parking lot. No reported maintenance program.
Smith, D.R. (2000). *Permeable interlocking concrete pavements: Selection, design, construction, maintenance.* Washington, D.C.: Interlocking Concrete Pavement Institute.	Literature review.	Design, construction, maintenance, and infiltration capacity guidelines developed by the Institute's technical committee from literature review.	Smith recommends 1.1-in/hr infiltration rate and a CN of 65 (all soil types) for permeable interlocking concrete pavements. Infiltration rate is for a 20-year life span.	
Borgwardt, S. (1997 February). Performance and fields of application for permeable paving systems. *Concrete Precasting Plant and Technology*, pp. 100-104.	Field evaluation of various driving surfaces in Europe.	Several permeable driving surfaces of various ages were evaluated using a drip infiltrometer.	Reports a durable infiltration rate of 4.25 in/hr.	No reported maintenance programs.
Pratt, C.J., Mantle, D.G., & Schofield, P.A. (1989). Urban stormwater reduction and quality improvement through the use of permeable pavements. *Water Science and Technology, 21*, pp. 769-778.	Field evaluation of experimental plots.	A 4.6m-wide by 40m-long by 350mm-deep (on average) parking area was excavated and divided into 4 trial areas. Each trial area was filled with a different type base aggregate and water quality and quantity measurements taken from under-drains. The wearing course was cement paving blocks and plots were lined with an impermeable membrane.	Three periods were measured during 30 days with a total rainfall of 80.5mm. The 350mm of various sub-base stone and pavers reduced the following amounts of the total precipitation: • Granite: 25% • Limestone: 39% • Blast furnace slag: 45% • Gravel: 37%	

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Brattebo, B.O., Booth, D.B. (2003, November). *Long-term stormwater quantity and quality performance of permeable pavement systems.* Water Research, 37, 4368-4376.	Field evaluation in Puget Sound.	Two plastic grid systems (1 filled with soil and grass and 1 with gravel), a concrete block lattice filled with soil and grass, and concrete blocks with gravel filled cells were installed in a parking lot in the city of Renton, WA. Each stall was evaluated for infiltration capability, infiltrate water quality, and durability. Two parking stalls with each type of permeable paving material and a conventional asphalt stall, for a control, were installed in 1996.	Surface runoff was measured throughout Nov. 2001 and from Jan. to early March 2002. Total rainfall during the collection period was 570mm delivered in 15 distinct precipitation events. The most intense storm event delivered 121mm of rain in 72 hours. The permeable stalls infiltrated virtually all stormwater. Surface runoff occurred for 6 events (other measurable surface runoff was detected, but attributed to leaks in the system). The most significant runoff volume of the 6 events was 4mm during the largest storm noted above (3% of total precipitation).	The permeable parking facility was monitored for the first year following construction. This study is a follow up to that work. The parking stalls were used constantly during the 6 years previous to this monitoring cycle. None of the permeable paving surfaces showed signs of major wear.
Dierkes, C., Kuhlmann, L., Kandasamy, J., & Angelis, G. (2002, September). Pollution retention capability and maintenance of permeable pavements. In *"Global solutions for urban drainage", Proceedings of the Ninth International Conference on Urban Drainage.* Portland, OR.	Field evaluation.	The infiltration rate of a parking stall in a 15-year old permeable paver installation in a shopping center was determined. The stall was then excavated to examine contaminant levels in the underlying base aggregate and soil. Stall was selected with high content of spilled oil on surface. A drip infiltrometer was used to measure infiltration rates.	The paving structure consisted of: pavers with 1-3 mm joints, 5-8 cm thick bedding material (2-5 mm), and a 20-25 cm base of crushed stone (8-45 mm). Infiltration rate: 440 liters/second/hectare in the central region of the stall and 2000l iters/second/hectare at the edges of the stall.	
Clausen, J.C., & Gilbert, J.K. (2003, September). *Annual report: Jordan Cove urban watershed section 319 national monitoring program project.* Storrs-Mansfield, CT: University of Connecticut, College of Agriculture and Natural Resources.	Field evaluation in southeastern Connecticut.	Two conventional asphalt, two conventional crushed aggregate, and two permeable paver (UNI group Eco-Stone) driveways were monitored during a 12-month period for runoff, infiltration rate, and pollutant discharge. Trench drains at the bottom of the driveways with tipping buckets measured runoff volume. Infiltration rates were assessed using 2 methods: a single ring infiltrometer and a perforated hose for a flowing test. Contributing area for each driveway and land cover type (roof, lawn, etc.) was assessed.	Infiltration rates for the permeable pavers: • Infiltrometer 2002: 7.7 in/hr. • Infiltrometer 2003: 6.0 in/hr. • Flowing infiltration 2003: 8.1 in/hr. • Runoff coefficient for pavers (runoff depth/rainfall depth) = 24%.	No maintenance program reported. The Eco-Stone driveways were two years old at the time of the study.

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Pervious Concrete				
Wingerter, R., & Paine, J.E. (1989). *Field performance investigation: Portland Cement Pervious Pavement.* Orlando, FL: Florida Concrete and Products Association.	Laboratory and field evaluation in Florida.	Test slabs of pervious concrete were poured, 18" cores removed, and infiltration rates tested. Cores were then clogged by adding 2" of sand and pressure washing for 1.5 hrs. Existing porous concrete installations were also evaluated by coring and measuring infiltration rates and percent of void space infiltrated by fines.	Laboratory core • Pre-clogging infiltration rate = 23.97 in/min. • Post-clogging infiltration rate with 1" sand remaining on surface = 3.66 in/min and 10.22in/min with sand removed from surface. Field tests • Naples FL restaurant parking lot 6.5 yrs. old: infiltration rate = 4 in/min, 3.4% infiltrated by fines. • Fort Myers parking area 8 yrs. old: infiltration rate = 7 in/min, 0.16% infiltrated by fines.	Analysis utilized falling head test that increases infiltration rates, however, rates far exceed any design storm infiltration need. No reported maintenance programs.
Maintenance				
Balades, J.D., Legret, M., & Madiec, H. (1995). Permeable pavements: Pollution management tools. *Water Science and Technology, 32,* 49-56.	Field evaluation in France.	Various street cleaning techniques were applied to different permeable pavements, including parking lots and roads with heavy traffic. Infiltration rates measured before and after cleaning.	Sweeping followed by suction: • Highly clogged surfaces (< 14 in/hr) no improvement. • Partially clogged surfaces (112–140 in/hr) original infiltration rates (210.60–224.64 in/hr) were obtained after two passes. Suction only • 1st site: initial infiltration rate = 7.02 in/hr, after two passes infiltration rate = 28.08 in/hr. • 2nd site: initial infiltration rate = 210.60 in/hr, after two passes infiltration rate = 280.80 in/hr. High pressure wash with suction • Shopping mall: initial infiltration rate = 9.83 in/hr (parking area) and 28 in/hr (roadway), after two passes infiltration rates = 84.24 in/hr for both parking and roadway. • Residential road: initial infiltration = approximately 0 in/hr, after treatment infiltration rate = 112 in/hr.	The analysis does suggest that restoring a percentage or all of the initial infiltration rate of a permeable pavement installation is possible. However, the type of permeable surface and the cleaning technique applied to that specific surface was not reported.

REFERENCE	STUDY SETTING	SUMMARY	FINDINGS	COMMENTS
Gerrits, C., & James, W. (2001). *Restoration of infiltration capacity of permeable pavers.* Master's thesis, University of Guelph. Guelph, Ontario, Canada.	Field evaluation of pervious paver (Eco-Stone) parking lot surfaces at University of Guelph in Ontario.	110 9m x 9m plots in the parking lot were tested for infiltration rates. Material in the drainage cells was excavated to various depths and tests repeated to evaluate regenerating infiltration capacity. Plots were categorized by low, medium and high average daily traffic, and paver bedding material. Parking lot was approximately 8 years old at time of research. Lot is sanded and plowed for snow during winter.	• 3" gravel bed: low traffic: initial = 5.85 in/hr excavate 20 mm = 7.8 in/hr med traffic: initial = 0.58 in/hr excavate 20 mm = 7.80 in/hr • 4" sand bed: low traffic: initial = 0.35 in/hr excavate 20 mm = 0.94 in/hr med traffic: initial = 0.12 in/hr excavate 20mm = no change	Authors find that vacuuming upper 5-20 mm of drainage cell material can regenerate infiltration, and that amounts of material removed to improve infiltration rates can be achieved by modern street sweeping equipment. Sand bed with high traffic most difficult to regenerate and medium traffic with gravel bed easiest to regenerate. Areas with pine needles and vegetation on drainage cells had higher infiltration rates than plots without vegetation material.
Dierkes, C., Kuhlmann, L., Kandasamy, J., & Angelis, G. (2002, September). Pollution retention capability and maintenance of permeable pavements. In *"Global solutions for urban drainage", Proceedings of the Ninth International Conference on Urban Drainage.* Portland, OR.	Field evaluation.	A high-pressure wash and vacuum street cleaning machine was used to clean a school yard permeable paver installation (approximately 4 yr old). The pavers were 10 cm x 20 cm x 8 cm installed on a 2-5 mm pea gravel leveling layer, and the joints filled with 1-3 mm basalt aggregate. Infiltration rates before and after cleaning were evaluated using a drip infiltrometer.	• Infiltration rate before cleaning at 3 selected points: less than 1 mm/second/hectare. • Infiltration rates after cleaning at same 3 points: 1545-5276 liters/second/hectare.	

Appendix 8

Permeable Hot-mix Asphalt Sample Specification

Origin: Cahill Associates, Westchester, Pennsylvania (Cahill Associates, Section 02725-General porous paving and groundwater infiltration beds, 2004).

Application: Parking lots with aggregate base for retention storage.

Soil infiltration rate: Required soil infiltration varies depending on contributing area, aggregate base storage and infiltration capacity, and design storm. In general, minimum long-term infiltration rate should be 0.1 inch/hour.

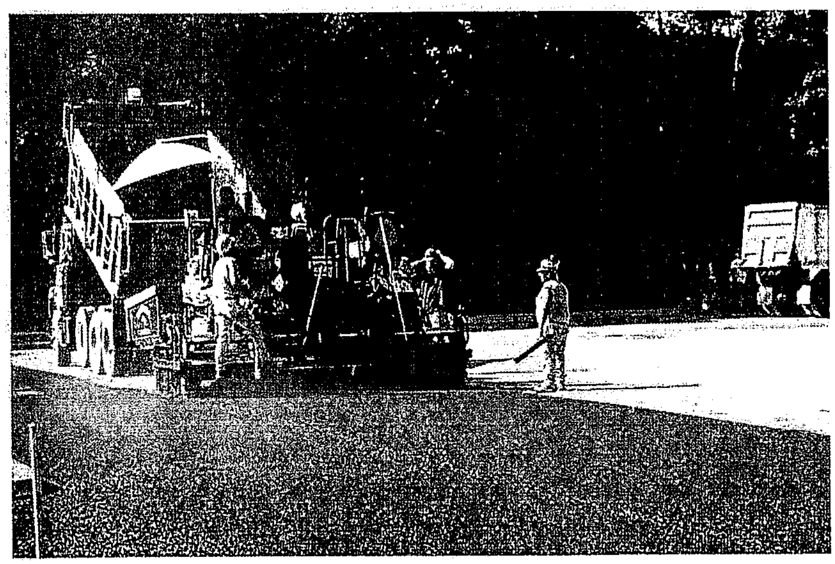

Figure 1 Parking installation, *Courtesy of Cahill Associates*

Top course: 2.5 inches thick

Aggregate grading:	U.S. Standard Sieve	Percent Passing
	1/2	100
	3/8	92-98
	4	32-38
	8	12-18
	16	7-13
	30	0-5
	200	0-3

A008046

Bituminous asphalt cement

- 5.75% to 6.00% by weight dry aggregate.
- Drain down of asphalt binder should be no greater than 0.3% in accordance of ASTM D6390.
- Use a neat asphalt binder modified with an elastomeric polymer to produce a binder meeting requirements of performance or PG 76-22 (PG recommendation for mid-Atlantic states).
- Elastomeric polymer is a styrene-butadiene-styrene or equal applied at a rate of 3% by total weight of the binder. Thoroughly blend polymer and binder at asphalt refinery prior to loading and transportation. The polymer modified asphalt binder should be heat and storage stable.
- Hydrated lime is added at a rate of 1.0% by weight of the total dry aggregate to mixes with granite stone to prevent separation of the asphalt from the aggregate and achieve a required tensile strength ratio of at least 80%. Hydrated lime should meet ASTM C 977.
- The asphalt mix should be tested for resistance to stripping by water in accordance with ASTM D 3625. If estimated coating area is not above 95%, anti-stripping agents should be added to the asphalt.

Asphalt installation

- Bituminous surface course mix is laid in one 2.5-inch lift directly over aggregate storage base.
- Laying temperature of the mix should be between 240 and 250 degrees Fahrenheit and ambient temperature should not be below 40 degrees Fahrenheit.
- Compaction of the surface course should occur when the surface is cool enough to resist a 10-ton roller. One or two passes is all that is required for proper compaction and additional rolling can cause a reduction in surface course porosity.

Aggregate base/storage bed material

- Coarse aggregate is 0.5- to 2.5-inch uniformly graded stone with a wash loss of no more than 0.5% (AASHTO size number 3).

Aggregate grading:

U.S. Standard Sieve	Percent Passing
2 ½"	100
2"	90-100
1 ½"	35-70
1"	0-15
½"	0-5

- Choker base course aggregate should be 3/8- to 3/4-inch uniformly graded stone with a wash loss of no more than 0.5% (AASHTO size number 57).

Aggregate grading:

U.S. Standard Sieve	Percent Passing
1 ½"	100
1"	95-100
½"	25-60
4	0-10
8	0-5

Aggregate base/storage installation

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- Existing subgrade under base should NOT be compacted or subject to excessive construction equipment traffic prior to installation.

- Storage bed should be excavated level to allow even distribution of water and maximize infiltration across parking entire area.
- Immediately before base aggregate and asphalt placement remove any accumulation of fine material from erosion with light equipment and scarify soil to a minimum depth of 6 inches.
- Geotextile fabric is a Mirafi 160N or approved equal. Overlap adjacent strips 16 inches and secure fabric 4 feet outside of storage bed to reduce sediment input to bottom of area.
- Install course (0.5 to 2.5 inch, AASHTO size number 3) aggregate in lifts no greater than 8 inches and lightly compact each lift.
- Install 1-inch choker course (No. 8 to 1.5-inch aggregate, AASHTO size number 57) evenly over surface of course aggregate base.
- Storage and infiltration bed depth will depend on infiltration rates, storage requirement and design storm; however, Cahill Associates often install 18- to 36-inch sections designed for full retention of storm flows.
- All erosion and sediment control should remain in place until area is completely stabilized with soil amendments, landscaping or other approved controls.

Backup systems

- For backup infiltration capacity (in case the asphalt top course becomes clogged) an unpaved stone edge is usually installed that is hydrologically connected to the storage bed (see Figure 2).

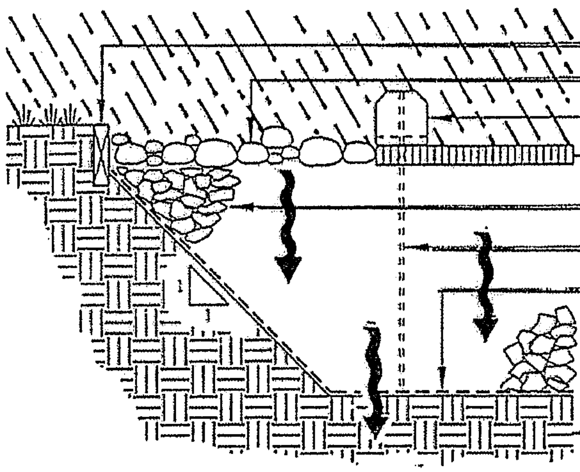

Figure 2 Backup infiltration system for permeable parking lot installations.
Graphic courtesy of Cahill Associates

- To ensure that the asphalt top course is not saturated from high water levels in the aggregate base (as a result of subgrade soil clogging), a positive overflow is usually installed.

Cahill Associates design some systems to infiltrate storm flows from adjacent buildings. Water is collected from roof downspouts, conveyed through a catch basin (to remove debris), and distributed in perforated pipes throughout the storage and infiltration aggregate base.

Appendix 9

Vegetated Roof Design Specification Example

Designers: Boxwood of Seattle, WA and Roofscapes Inc., Philadelphia, PA.
Roof location: Point Defiance Zoo animal health care facility, Tacoma. WA.

The specification that follows is provided by Boxwood of Seattle and Roofscapes, Inc., and was used in the construction of this vegetated roof.

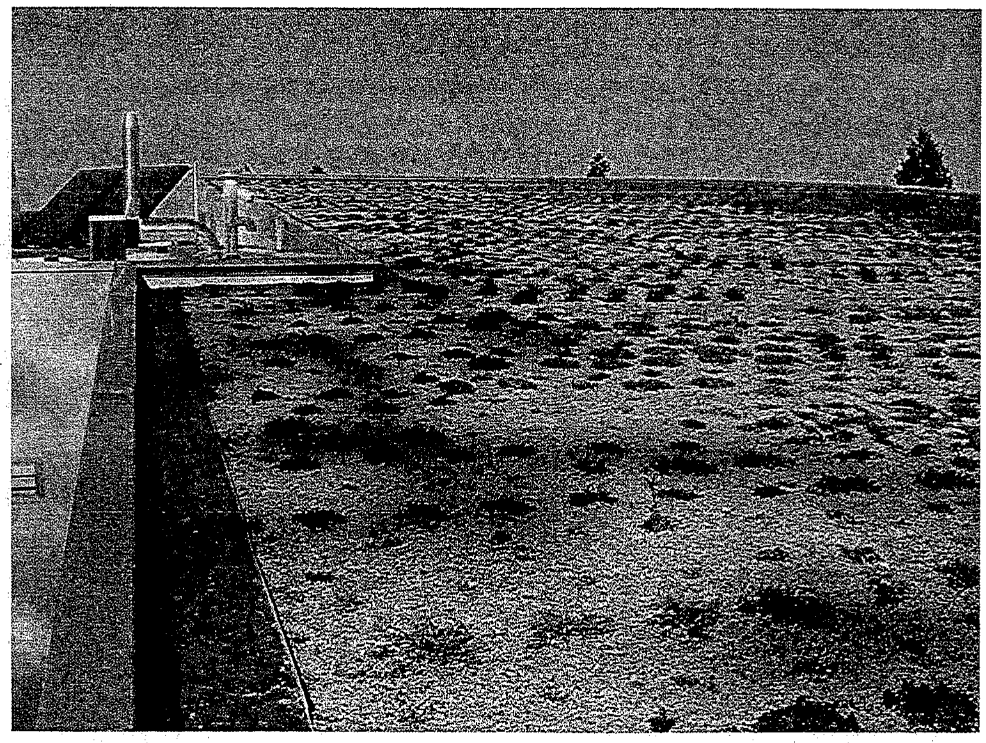

Figure 1 Vegetated roof at Point Defiance Zoo animal health care facility. *Photo by Curtis Hinman*

Summary

- The vegetated cover is a two-layer system, consisting of a 2.5-inch growth media layer installed over the Meadowflor™ drainage system. The weight of this system at Maximum Water Capacity and with rainfall runoff occurring is less than or equal to 15 pounds per square foot.
- The system is not irrigated. However, it may require periodic hand watering during the initial 12 months of the establishment period.

Thermoplastic Sheet Waterproofing Membrane

- Materials:
  - Sarnafil G476 fiberglass reinforced membrane and compatible sealant.
  - Minimum thickness: 60 mils.
  - All roofing components should be compatible with the membrane.
- Quality Assurance:
  - Only an approved contractor authorized by the manufacturer prior to bid should apply the waterproofing system.
  - Installation of waterproofing membrane, flashing, membrane expansion joints, membrane containment grids, membrane protection layers, drainage layer and insulation should be the responsibility of the membrane applicator to ensure undivided responsibility.
  - Obtain primary waterproofing materials, membrane, and flashing from a single manufacturer with not less than 10 years of successful experience in waterproofing applications. Provide other system components only as approved by manufacturer of primary materials.
  - Waterproofing contractor should arrange with the membrane manufacturer to have the services of a competent field representative at the site to accept the substrate surface before installation of waterproofing materials. The field representative of the membrane manufacturer should check and test all heat-welded seams before the water test, and prior to installation of separation and protection layers.
  - Before construction begins the owner, architect, contractor's field superintendent, waterproofing foreman, waterproofing membrane manufacturer's field representative, and other involved trades should meet to discuss waterproofing practices applicable to this project.
  - There should be no deviation made from the contract specification or the approved shop drawings without prior written approval by the owner, the owner's representative and/or design professional, and membrane manufacturer.
  - Water testing of the completed waterproofing system should be for a minimum of 24 hours. Water testing should be witnessed and confirmed in writing by the owner's representative and/or design professional, the waterproofing contractor, and membrane manufacturer.
  - Trained and authorized personnel should complete all work.
- Installation
  - The surface substrate should be clean, dry, free from debris, and smooth with no surface roughness or contamination. Broken, delaminated, wet or damaged insulation or recover boards should be removed and replaced.
  - Overlap rolls by 3 inches. Shingle seam overlaps with the flow of draining rainwater when possible.
  - Hot-air welding of seam overlaps:
    - ✓ Seams should be 3-inch when using an automatic machine welding, and 4-inch when hand welding.
    - ✓ All membrane to be welded should be clean and dry. Follow manufacturer's specifications for welding.
  - Flashings: all flashings should be installed concurrently with the waterproofing membrane as the job progresses per manufacturer's directions. No temporary flashings will be allowed. All flashings should be inspected and accepted by the membrane manufacturer.
  - Temporary cut off: when a break in the day's work occurs, install a temporary watertight seal by sealing the membrane to the deck or substrate. When work resumes, the contaminated membrane should be removed. If any water is allowed to enter under the completed waterproofing, the affected area should be removed and replaced at the contractor's expense.
  - Membrane is incompatible with asphalt, oil-based and plastic-based cements, creosote and penta-based materials. If contact occurs, the material should be cut out and discarded. The

contractor should consult the manufacturer with respect to material compatibility, precautions, and recommendations.

- o Contaminants, such as grease, fats, oils, and solvents, should not be allowed to come into direct contact with the waterproofing membrane.

Protection Fabric

- Material: 22-ounce per square yard polypropylene non-woven needled geotextile.
- The surface of the waterproofing system should be swept and washed.
- Until the drain sheet is installed, traffic over the working area should be strictly controlled and limited to essential personnel only.
- Heavily traveled areas (e.g., corridors for transporting material to the working areas) must be protected in a manner approved by the waterproofing installer.
- Suitably protect lay-down areas using ½-inch plywood over 1-inch sheets of expanded polystyrene, or similar sheathing material.
- Roll out the protection fabric on top of the completed waterproofing system.
- Overlap seams a minimum of 6 inches and tack seams using a hot-air welding gun (Leister, or equivalent).

MEADOWFLOR™ Drainage System

- The vegetated cover system should be underlain everywhere by the Meadowflor™ system. This consists of:
  - o Roofmeadow® perforated polyethylene drain sheet with adhered polypropylene separation fabric. The sheet is a dimpled sheet. The composite system satisfies the following specifications:

Membrane thickness	≥ 20 mil
Compressive strength	≥ 5,200 lb/ft²
Tensile strength (ASTM-D4594)	≥ 1,000 lb/ft
Brittleness temperature (ASTM-D746)	≤ -50° F
Softening temperature	≥ 250° F
Transmissivity (between platens)	≥ 24 gal/min/ft
Permittivity (ASTM-D4491)	≥1.5 sec⁻¹
Height (varies according to position)	0.39 to 0.78 in

  - o Separation Fabric
    - ✓ Needled non-woven polypropylene geotextile fabric. This component should satisfy the following specifications:

Unit Weight (ASTM-D5261)	≥ 4.25 oz/yd²
Puncture Resistance (ASTM-D4833)	≥ 35 lbs
Mullen Burst Strength (ASTM-D4632)	≥ 135 lb/in
Permittivity (ASTM-D4491)	≥ 1.5 sec⁻¹

- Install the drain sheet, together with separation sheet. The drain sheet should be installed with the studs and fabric layer facing up to enhance rapid drainage of the overlying media.
- Assemble the perforated conduit on top of the drain sheet, as shown on the drawings.
- Weigh down the drainage layer with temporary ballast, as necessary.

Border Elements

- Roofmeadow® cantilever, fabricated from 1/8-inch aluminum.
- Height: ≥ 0.25 inch higher than the top of the growth media layer.
- Base Length: 7 inches, or 1.5 times the height of the element, whichever is greater.
- Install border elements as required to prevent mixing of ballast and growth media.

Growth Media Layer

- Roofmeadow® Type M1 Extensive Growth Media. This material is a mixture of mineral and organic components that satisfies the following specifications:
  - Void ratio at Field Capacity (0.333 bar) ≥ 15% (vol)
  - Moisture content at Field Capacity ≥ 10% (vol)
  - Maximum Water Capacity ≥ 20% (vol)
  - Density at Maximum Water Capacity ≤ 62 lb/ft^3
  - Saturated Hydraulic Conductivity ≥ 1.5 in/hr, and ≤ 15.0 in/hr
  - Volatile fraction (organic matter) ≤ 10% (dry wt.)
  - pH 5.5 - 7.9
  - Soluble salts ≤ 0.30 mmhos/cm (1:20 dilution)
  - Grain-size distribution of the <u>mineral fraction</u> (ASTM-D422)

Clay fraction (2 micron)	≤ 1%
Pct. Passing US#200sieve	≤ 5% (i.e., silt fraction)
Pct. Passing US#60 sieve	≤ 10%
Pct. Passing US#18 sieve	5 - 50%
Pct. Passing 1/8-inch sieve	20 - 70%
Pct. Passing 3/8-inch sieve	75 -100%

- Macro and micronutrients should be incorporated in the formulation in initial proportions suitable to support the specified planting.
- Thoroughly blend at a batch facility. Moisten, as required, to prevent separation and loss of fine particles during installation.
- Quality control samples should be collected and submitted for testing for each 100 CY provided to the job.
- Placing the growth media layer: The media should be dispensed at the roof level in a manner that will not suddenly increase the load to the roof. It should be immediately spread to the specified thickness, plus 10 percent (after moderate compaction).
- Set the media back from the curbs and parapets as directed in the specifications. The set back for this project is 12 inches. At the margins of the media spread a 2-foot wide strip of separation fabric.
- Cover the media layer with the wind blanket and secure, unless direct seeding (see below).
- Thoroughly soak with water using a sprinkler or hand sprayer. For a 4-inch growth media layer, expect to use about 30 gallons per 100 square feet.

Gravel Margin

- Fill the area between the flashed wall and growth media with gravel as specified.

Planting (plug installation)

- The following plant list should be installed. Any alternatives must be approved by the green roof installer.
- All extensive planting schemes must incorporate *Sedum* species. *Sedum* must represent at least 50 percent of the installed plants. Additionally, the plant mixture should include a minimum of four different species of *Sedum* in approximately equal quantities.
- Non-*Sedum* varieties should be selected that are adapted to the specific growing conditions.
- Plant installation should occur May-June or September-October, unless an active irrigation system is included.
- Plants should be established from 32-cell plugs propagated in sterile nursery medium, according to the plant provider's recommendations. Plugs larger than this can be used; however, the establishment rate is typically better with the smaller plants. The recommended minimum planting rate is 640 plants per 1000 square feet.
- Thoroughly soak the growth media prior to planting.
- The plugs should be set into the media to their full depth and the media pressed firmly around the installed plug. At the end of each day, soak those areas that have been newly planted.
- Do not mulch.

Plant List:

Allium schoenprasm

Delopserma nubigenum

D. cooperii

Echeveria sp.

Petrohagia saxifraga

Sedum floriferum

S. album

S. sexangulare

S. spurium roseum

S. pinofolium

S. reflexum

S. sarmentosum

S. boehmii (orostachys)

Sempervivum sp.

Wind Blanket

- Roofmeadow® photo/bio-degradable covering is used to protect the media from wind erosion during the 24-month plant establishment period. The provider must demonstrate that the wind blanket will remain securely in place during high winds and that it will not interfere with the growth of the plants. It must satisfy the following specifications:
  - Aperture — ≥ 0.04 in, and ≤ 0.125 inch
  - Tensile strength — (ASTM D4632) ≥ 20 lb
  - Satisfies smolder resistance criteria — (FTMA-CCC-%-191B)
- The Roofmeadow® Wind Blanket includes a method for firmly securing the protective layer to the green roof system.

Glossary

Advection	Transfer or change of a property of the atmosphere (e.g., humidity) by the horizontal movement of a mass of fluid (e.g., air current).
Allelopathic	Suppression of growth of one plant species as a result of the release of a toxic substance by another plant species.
Ammonification	Process in which organic forms of nitrogen (e.g., nitrogen present in dead plant material compounds) are converted to ammonium ($NH4^+$) by decomposing bacteria.
Bankful discharge	Stream discharge that fills the channel to the top of the banks and just begins to spread onto the floodplain. Bankful discharges occur on average every 1 to 1.5 years in undisturbed watersheds and are primarily responsible for controlling the shape and form of natural channels.
Bedload	Sediment particles that are transported as a result of shear stress created by flowing water, and which move along, and are in frequent contact with, the streambed.
Biotic integrity	Condition where the biologic or living community of an aquatic or terrestrial system is unimpaired and species diversity and richness expected for that system are present.
Bole	Trunk of a tree.
California Bearing Ratio	Test using a plunger of a specific area to penetrate a soil sample to determine the load bearing strength of a road subgrade.
Cation exchange capacity	Amount of exchangeable cations that a soil can adsorb at pH 7.0 expressed in terms of milliequivalents per 100 grams of soil (me/100 g).
Compost maturity	Term used to define the effect that compost has on plant growth. Mature compost will enhance plant growth; immature compost can inhibit plant growth.
Compost stability	Level of microbial activity in compost that is measured by the amount of carbon dioxide produced by a sample in a sealed container over a given period of time.
Critical shear stress	Lift and drag forces that move sediment particles. Forces are created as faster moving water flows past slower water.
Denitrification	Reduction of nitrate (commonly by bacteria) to di-nitrogen gas.

Desorb	To remove (a sorbed substance) by the reverse of adsorption or absorption.
Diurnal oxygen fluctuations	Fluctuations in dissolved oxygen in water as photosynthetic activity increases during the day and decreases during the night.
Effective impervious area (EIA)	Subset of total impervious area that is hydrologically connected via sheet flow or discrete conveyance to a drainage system or receiving body of water. The Washington State Department of Ecology considers impervious areas in residential development to be ineffective if the runoff is dispersed through at least 100 feet of native vegetation using approved dispersion techniques.
Endocrine disruptors	Substances that stop the production or block the transmission of hormones in the body.
Evapotranspiration	Collective term for the processes of water returning to the atmosphere via interception and evaporation from plant surfaces and transpiration through plant leaves.
Exfiltration	Movement of soil water from an infiltration integrated management practice to surrounding soil.
Exudates	Substances exuded from plant roots that can alter the chemical, physical and biological structure of the surrounding soil.
Hydrologically functional landscape	Term used to describe a design approach for the built environment that attempts to more closely mimic the overland and subsurface flow, infiltration, storage, evapotranspiration, and time of concentration characteristic of the native landscape of the area.
Hydroperiod	Seasonal occurrence of flooding and/or soil saturation that encompasses the depth, frequency, duration, and seasonal pattern of inundation.
In-line bioretention	Bioretention area that has a separate inlet and outlet.
Invert	Lowest point on the inside of a sewer or other conduit.
Liquefaction	Temporary transformation of a soil mass of soil or sediment into a fluid mass. Liquefaction occurs when the cohesion of particles in the soil or sediment is lost.
Mycorrhizal	Symbiotic association of the mycelium of a fungus with the roots of a seed plant.
Nitrification	Process in which ammonium is converted to nitrite and then nitrate by specialized bacteria.
Off-line bioretention	Bioretention area where water enters and exits through the same location.

Phytoremediation	The utilization of vascular plants, algae and fungi to control, break down, or remove wastes, or to encourage degradation of contaminants in the rhizosphere (the region surrounding the root of the plant).
Reaction range	Length of the pin or pile in a minimal excavation foundation system that is in direct contact with and bears against the soil to support the above-ground structure.
Saturated hydraulic conductivity	Ability of a fluid to flow through a porous medium under saturated conditions; is determined by the size and shape of the pore spaces in the medium, their degree of interconnection, and by the viscosity of the fluid. Hydraulic conductivity can be expressed as the volume of fluid that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.
Seral stage	Any stage of development or series of changes occurring in the ecological succession of an ecosystem or plant community from a disturbed, un-vegetated state to a climax plant community.
Soil bulk density	Ratio of the mass of a given soil sample to the bulk volume of the sample.
Soil stratigraphy	Sequence, spacing, composition, and spatial distribution of sedimentary deposits and soil strata (layers).
Stage excursions	Departures, or changes, in pre-development water depth (either higher or lower) that occur after development takes place.
Threshold discharge area	Onsite area draining to a single natural discharge location or multiple natural discharge locations that combine within one-quarter mile downstream (as determined by the shortest flow path).
Time of concentration	Time that surface runoff takes to reach the outlet of a sub-basin or drainage area from the most hydraulically distant point in that drainage area.
Total impervious area (TIA)	Total area of surfaces on a developed site that inhibit infiltration of stormwater. The surfaces include, but are not limited to, conventional asphalt or concrete roads, driveways, parking lots, sidewalks or alleys, and rooftops.
Transmissivity	Term that relates to movement of water through an aquifer. Transmissivity is equal to the product of the aquifer's permeability and thickness (m^2/sec).
Tree canopy dripline	Outer most perimeter of a tree canopy; defined on the ground by a vertical line from the perimeter of the leaves of a tree canopy to the ground directly below.

Frequently used acronyms

AASHTO............American Association of State Highway and Transportation Officials

ASTM.................American Society for Testing and Materials

CEC ....Cation exchange capacity

CN.....................Curve number

CRZ ....Critical root zone

IMPs ....Integrated management practices

SMMWW ....*Stormwater Management Manual for Western Washington*

USDA.................United States Department of Agriculture

WAC ....Washington Administrative Code

WWHM.............Western Washington Hydrologic Model

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Low Impact Development Technologies

by Anne Guillette, LEED Accredited Professional
Low Impact Design Studio (formerly with the Low Impact Development Center)

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Building Types
Space Types
Design Objectives
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Project Management
Delivery Teams
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INTRODUCTION

Related Resource Pages Pı

A. Low Impact Development: An Alternative Site Design Strategy

Low Impact Development (LID) is an alternative site design strategy that ı and engineered infiltration and storage techniques to control storm water generated. LID combines conservation practices with distributed storm wa controls and pollution prevention to maintain or restore watershed functioı objective is to disperse LID devices *uniformly* across a site to minimize rur

LID reintroduces the hydrologic and environmental functions that are alter conventional storm water management. LID helps to maintain the water b site and reduces the detrimental effects that traditional end-of-pipe syster waterways and the groundwater supply. LID devices provide temporary re areas; increase infiltration; allow for nutrient (pollutant) removal; and con release of storm water into adjacent waterways.

Some examples of LID technologies include:

- ***Engineered systems*** that filter storm water from parking lots and surfaces, such as bio-retention cells, filter strips, and tree box filters
- ***Engineered systems*** that retain (or store) storm water and slowly water, such as sub-surface collection facilities under parking lots, bi cells, and infiltration trenches;

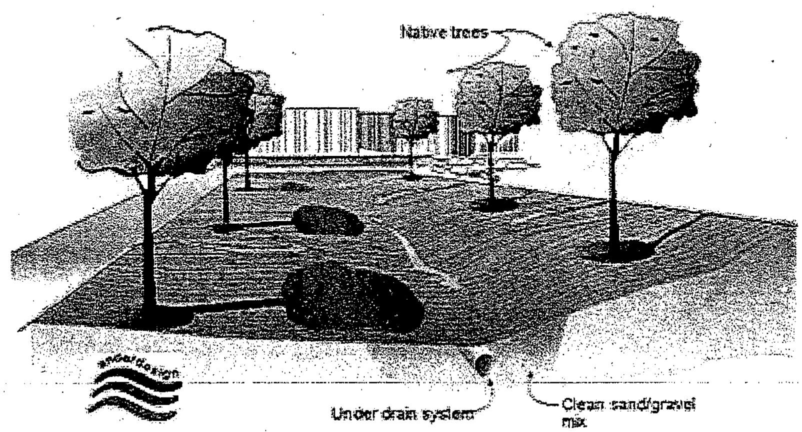


Fig. 1: Bio-swale schematic
Courtesy Pierce County, /WSU Extension

- ***Modifications to infrastructure*** to decrease the amount of impen surfaces such as curbless, gutterless, and reduced width streets;

- ***Low-tech vegetated areas*** that filter, direct, and retain storm wat rain gardens and bio-swales;
- ***Innovative materials*** that help break up (disconnect) impervious : are made of recycled material such as porous concrete, permeable p site furnishings made of recycled waste;
- ***Water collection systems*** such as subsurface collection facilities, · rain barrels; and
- ***Native or site-appropriate vegetation.***

B. Conventional Design

Figs. 2-3, *Left to right:* Conventional and LID site design comparison
Courtesy PGDER

Conventional storm water management techniques direct all of the storm ' storm drains to remove it from the site as quickly as possible. End-of-pipe , are typically designed to store and detain runoff to reduce peak flows for s events that are infrequent, such as the 10 year, 24-hour storm. Controls a not in place to reduce flows for smaller, more frequently occurring events. also are not structured to address non-point source pollution problems or ' the groundwater. Since runoff needs to be managed on the site, large pon series of ponds, are required. These controls take up a significant portion (

Storm water ponds are characteristically constructed with fences around tl periphery for health and safety reasons. The outbreak of the West Nile viru concern about fecal droppings of migratory birds has heightened concern a suitability and maintenance of retention ponds. Ponds require annual mair and can require expensive long-term rehabilitation costs.

In contrast, the requirement for storm water retention is achieved with LII the use of distributed controls. The retention areas are designed into the c or below existing infrastructure (such as parking lots), and create opportu new design configurations that are less dependent on inlets, pipes, and po Additionally, LID technologies eliminate the need for costly maintenance c typically requiring only routine landscape maintenance, with the exception engineered systems such as tree box filters and sand filters.

The graphics show a conventional site design and a LID site design. The L illustrates the potential for innovative site design alternatives with the elin retention ponds. The comparison exemplifies how land used for retention | be allocated differently with the implementation of a distributed storm wat program.

C. Economic Indicators and the "Greening" Movement

Economic indicators signify a shift in consumer and corporate purchasing t "green" building. Homeowners are willing to pay a higher premium for hor more energy efficient and for properties that are adjacent to open space. I corporations are inclined to spend more on energy-efficient buildings with site amenities as they improve employee performance. This is causing bui developers, and product manufacturers to take notice. LID can assist in re bottom line while providing significant environmental benefits.

Some benefits of a LID site design strategy include:

- Reduced infrastructural costs for ponds, curbs and gutters, inlets, ar
- Increased lot yield,
- Reduced life-cycle costs,
- Increased marketability, and
- Increased property values.

D. Examples of Profitable LID Development

1) Somerset Community—A $916,382 Cost Savings

One of the oldest communities in the United States to implement LID on a is the Somerset Community in Prince Georges County, Maryland. The deve successfully integrated LID technologies into the 60-acre development in 1 199 homes were sited on 10,000 square foot lots. The alternative develop pattern that used distributed storm water management systems yielded 6 lots, which resulted in increased revenues at $40,000 each. The final cost was:

a. $300,000 savings on LID vs. storm water ponds
   LID Cost: $100,000
   Conventional Cost: $400,000
b. $240,000 additional revenue on 6 additional lots (space previously a ponds) 6 lots x $40,000 Net
c. $916,382 overall cost savings or $4,600 savings per lot

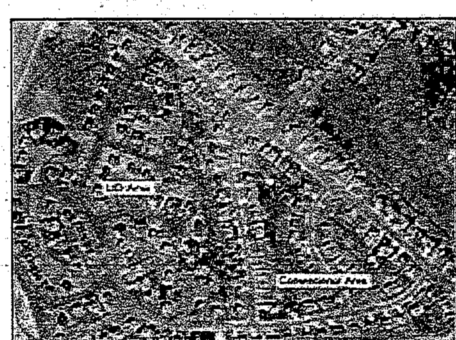


Fig. 4: Aerial view of Somerset Commu
Courtesy PGDER

The streets in Somerset have no curbs or gutters and use shallow swales a the streets to store and infiltrate storm water. Every lawn has a bio-retent rain garden). The swales and bio-retention cells are important because the the first flush of a storm, which contains the greatest amount of pollutants allow the water to be stored (for less than 24 hours) and infiltrate into the conventional system does not filter the storm water from the streets and s amounts of untreated water into nearby waterways, via one or more deter

The downspouts of the roofs direct rainwater into vegetated areas or rain groundwater supply is recharged and collected rainwater satisfies irrigatio Community cooperation has been positive as the residents understand the preserving the Chesapeake Bay. Ongoing community participation and upl bio-retention cells has been positive, as shown in the recent photos.

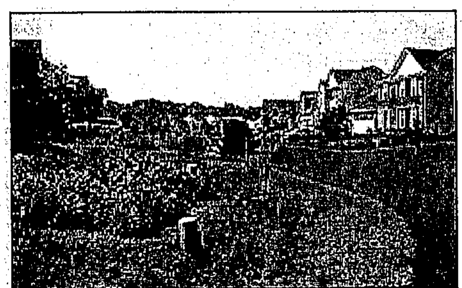
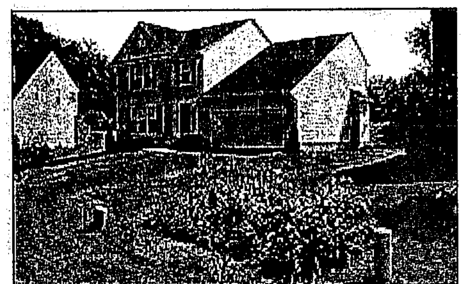



Fig. 5-6: Bio-retention cells in Somerset Community
Photo Credit: The Low Impact Development Center

Although the streets do not have curbs and gutters, they are exceptionally due to building regulations at the time of development. This is not a recon practice; minimizing impervious cover is a LID concept. Eliminating one la street parking in this subdivision could have resulted in a substantial savir

2) Northridge Community—The Sustainable Alternative

Northridge Community, also in Prince Georges County, Maryland, is an ex subdivision with reduced street widths, bio-swales adjacent to curbless str substantial tree preservation program. In 1988 the developer, Michael T. I $23 million dollars on the 855 unit, 356 acre development. In lieu of conv infrastructure costs (wider streets, detention ponds, catch basins, curbs a the developer spent the cost differential on a community center, a lake, a additional open space. Although a regulatory and permitting challenge, th was instrumental in advancing forest conservation programs and the use c technologies.

Northridge has received a considerable amount of certificates and awards environmental and business realms.

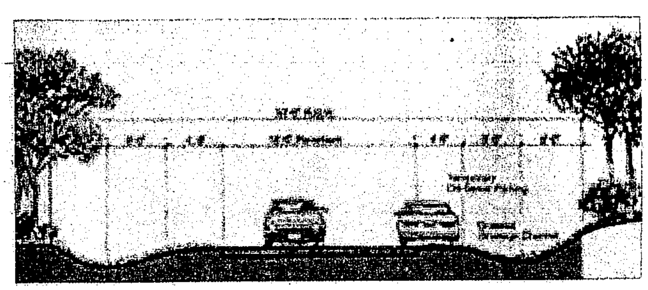



Fig. 7-8: Curbless roads and amenities in Northridge Community
Courtesy of The Michael T. Rose Family of Companies

E. Benefits of the LID Site Design Strategy

Benefits of LID:
1. Reduce infrastructural costs for ponds, curbs, and gutters
2. Increase the lot yield
3. Reduce life-cycle costs,
4. Increase marketability, and
5. Increase property values.

1) LID Reduces Infrastructure Costs and Increases Lot Yield

In the LID site design strategy buildings, roads, sidewalks, and open spac for multiple purposes and are designed to maximize site functions. The us distributed LID technologies reduces or eliminates the need for large-scale pipe systems and thus reduces the infrastructural costs of a network of pi gutters, and ponds. Space traditionally set aside for detention ponds can r designated for an alternative use, such as architectural, entertainment/rec or reforestation/conservation.

Small-scale LID technologies are positioned in precise locations to accomp water quality or water quantity objectives. (See Table 1 below.) The most location of the devices is close to the source. For example, bio-retention c gardens) are located adjacent to parking lots so that they can filter and tr directly. Tree box filters are located on streets that require curbs and gutt and treat surface runoff before it enters the waterways. Vegetated swales adjacent to curbless roads and are effective at filtering and infiltrating sto and recharging the groundwater supply. Rain barrels or cisterns collect rai rooftops to irrigate landscaped areas. Subsurface collection facilities (unde lots or sidewalks) constructed at varying depths accommodate large storm retain and/or store water for reuse or for slow-release infiltration.

2) Enhanced Livability = Increased Property Value

Improved site design has a direct correlation to enhanced livability and co aesthetics. LID not only facilitates the stabilization of the hydrologic condi site, but it improves the market appreciation.

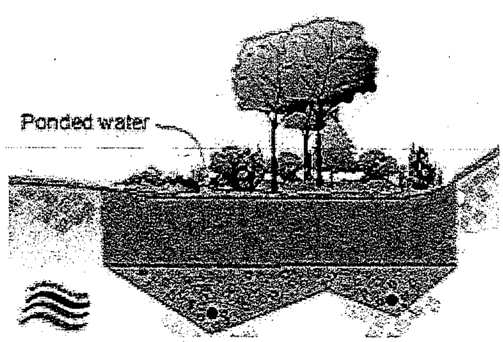


Fig. 9: Open space is used for storm control via a Bio-retention Cell
Courtesy Pierce County, WA/WSU Ex

The management of the site through the distributed controls allows for unprecedented design schemes. Consider the intangible benefits that resu "whole site design controls" as shown in the graphic to the right. It demor a bio-retention cell can be constructed to provide retention and also beaut space. The graphic below illustrates how space can be used for multiple pı common area between homes that accommodates a bio-retention cell to s infiltrate water during storms, is suitable for light recreation (e.g., walking during dry periods.

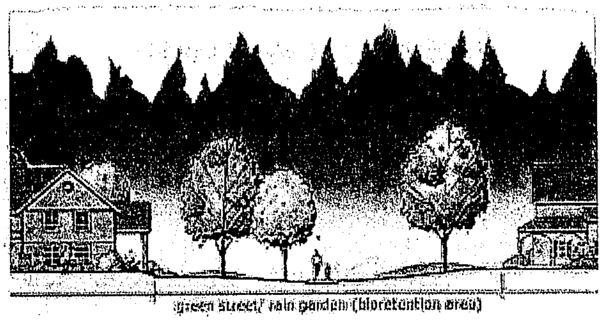


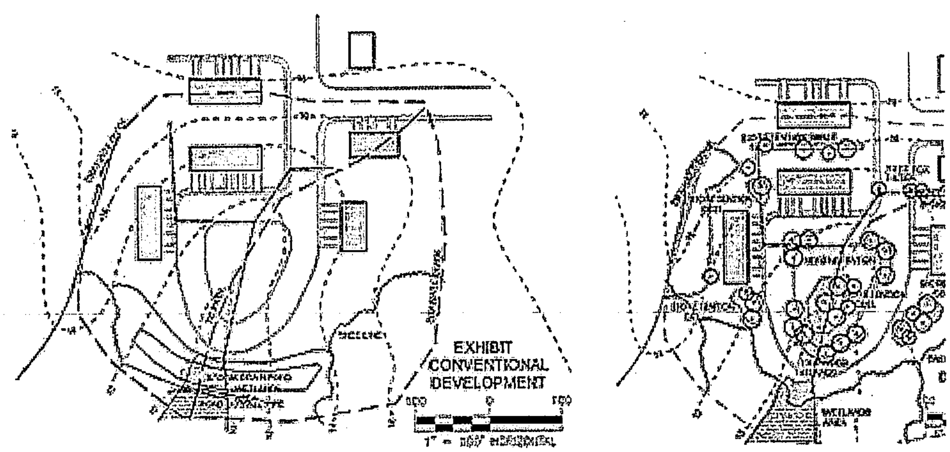
Fig. 10: A Bio-retention cell ‹ for light recreation
Courtesy Pierce County, Was AHBL, Inc.

F. LID Site Design Examples

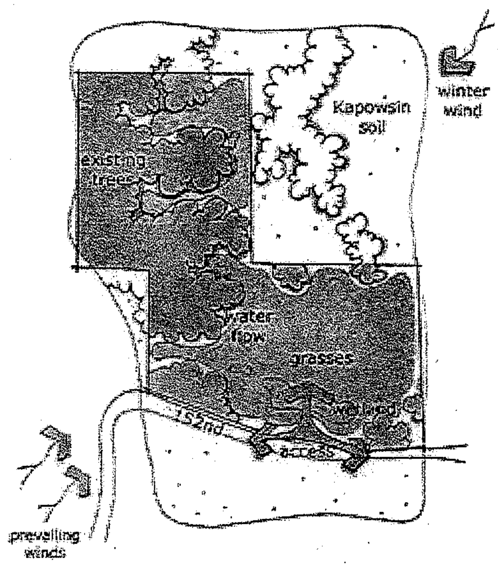
1) Community Design—Townhomes

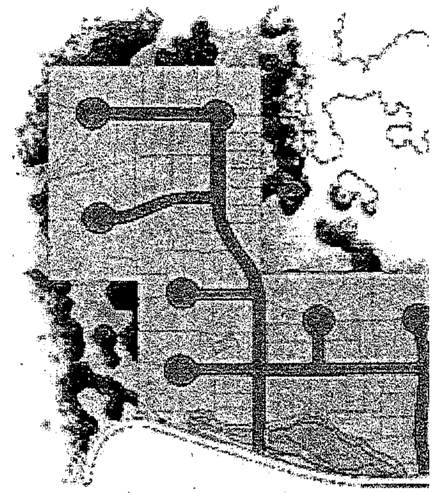
These illustrations compare a conventional site design with a LID site desi building footprint and circulation are identical in each. The LID site design the unique conditions of the site and uses an arrangement of distributed L to meet storm water management requirements. It also utilizes the existir to function as a natural filtration zone, as they have historically. There is r add a retention pond, as the site is configured to make an allowance for tł impervious surfaces and balance the hydrologic requirements.

The site is arranged with rain gardens, bio-retention cells, and bio-swales. options not represented in this site design include reduced street widths, c roads, permeable parking bays, permeable sidewalks, cisterns, and rain bı



Figs. 11-12: Site design comparison
Courtesy PGDER



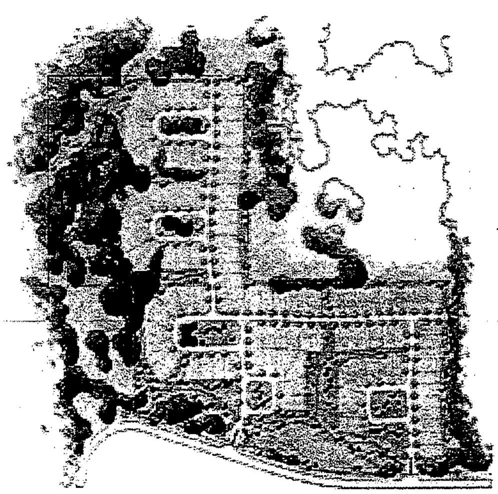


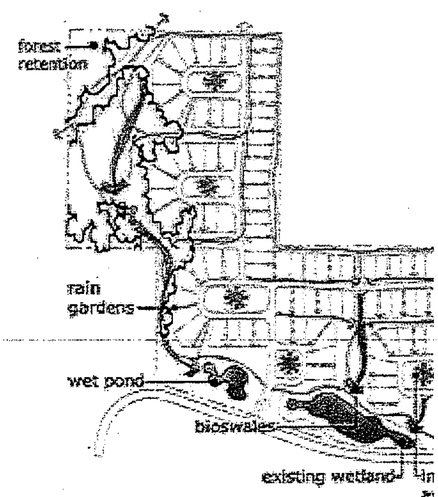
Left: Fig. 13: Site inventory *and Right:* Fig. 14: Conventional site design
Images courtesy Pierce County, Washington and AHBL, Inc.

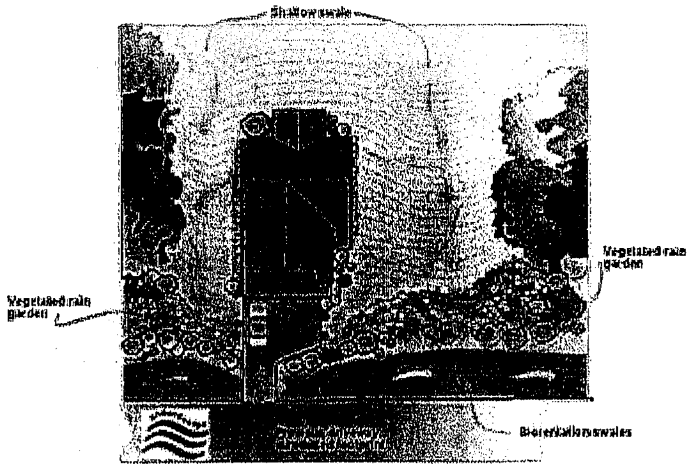
2) Community Design—Single Family Homes

Pierce County, Washington, developed a storm water management manua
developers, engineers, planners, and designers that demonstrate the LID :
strategy. The drawings were produced for Kensington Estates community
the conventional design approach with the LID design. The project also inc
thorough cost comparison.

The 24-acre development yielded 103 lots with the conventional scheme.
redesign, which integrated conservation practices, yielded 103 lots at 4 ur
acre. This design preserved the density while designating half of the site a
space. The cost comparison showed that the LID design achieved a 20% c
on construction.







Left above: Fig. 15: design; *Right above:* Site drainage patterr Fig. 17: LID lot desiç Images courtesy Pie Washington and AHE

Fig. 13 illustrates the site inventory with existing vegetation, wind pattern drainage patterns, soil types, and view sheds.

Fig. 14 shows a conventional development pattern with roads and lots pla land to maximize the available space. The existing hydrologic patterns are preserved, nor are the existing forests conserved. The storm water will be in a conventional manner.

Fig. 15 shows a LID design strategy. The existing natural resources are th departure for the design: the placement of lots, roads, and open space is existing drainage patterns and forested areas. The decision to design with composition influenced the lot size. In the LID scheme it was determined t best use of the property was smaller lots and greater density.

Fig. 16 shows the overall LID drainage pattern. The open space is designa infiltration/overflow area. The hydrologic integrity of the site is maintainec conforming the development to pre-development patterns.

Each lot in the community manages storm water for the most frequent stc at the source with rain gardens, swales, bio-retention cells, pervious drive conservation areas, as seen in Fig.17. However, engineered swales and in areas (typically in the open space) are integrated into the design to accor large storms.

The developer pursued the conventional scheme, but in the end had to pu additional acres off-site to achieve the required storm water management They were fortunate to have been grandfathered in under the old storm d Otherwise the current regulations would have required them to purchase 6 acres and lose 10 housing units at a cost of $1 million. The LID cost savin the new storm drain rules are even more significant.

G. The Storm Water Utility Fee

Of concern to developers, designers, and engineers is the national trend t water utility fees, or taxes, for storm water that exits a property. Fees are calculated on the impervious area of a lot, such as roofs, roads, and drive\ will reduce or eliminate storm water utility fees by reducing impervious su mitigating their impact, promoting infiltration, and dispersing flows. LID si lowers the volume of runoff leaving a site. This should be considered as ar cost savings beyond reduced maintenance costs.

H. LID: An Urban, Suburban, or Rural Solution

LID can be incorporated into any development scenario, whether urban, u suburban, or rural. The range of sizes and scales of the devices allows for configurations even where space is limited. LID is particularly effective for non-point source pollution in dense, urban areas, because the LID control: used below paved surfaces, in easements or right-of-ways, and in open sp increase the site's storage and infiltration capacity.

DESCRIPTION OF LID TECHNOLOGIES

A. LID Practices and Benefits

The LID site design approach is a precise arrangement of natural and engi technologies. The devices, or Integrated Management Practices (IMPs), fu comprehensive system across the site to achieve the goals of:

- Peak flow control
- Volume reduction
- Water quality improvement (filter and treat pollutants), and
- Water conservation.

Table 1 illustrates several LID technologies and their associated benefit(s) description of commonly used LID practices and suitable applications follo\

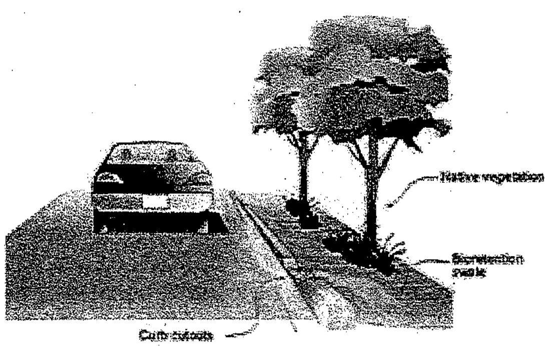


Fig. 18: Curb cut schematic
Courtesy Pierce County, Washing
AHBL, Inc.

Table 1: LID Practices and Benefits

LID PRACTICE / DEVICE	Peak Flow Control	Volume Reduction	Water Quality Improvement	Co
Bio-retention Cell	•	•	•	
Cistern	•	•		

Curbless Parking Lot Islands	•	•	•	
Downspout Disconnection	•	•	•	
Grassed Swale	•	•	•	
Green Roof	•		•	
Infiltration Trench	•	•	•	
Narrow Road Design	•	•	•	
Permeable Pavers/Pavement	•	•	•	
Rain Barrel	•	•		
Rain Garden	•	•	•	
Sand Filter	•		•	
Tree Box Filter	•		•	
Tree Planting	•	•		

B. Common LID Practices

Below are examples of common LID practices. A brief overview of the stor controls that can be implemented on a project is also included. The techni be evaluated for their suitability for each project.

1) Bio-retention Cell (Rain Garden)

A bio-retention cell (strip or trench) is an engineered natural treatment sy consisting of a slightly recessed landscaped area constructed with a specia mixture, an aggregate base, an underdrain, and site-appropriate plant ma tolerate both moist and dry conditions. The site is graded to intercept runc paved areas, swales, or roof leaders. The soil and plants filter and store ru remove petroleum products, nutrients, metals, and sediments, and promo groundwater recharge through infiltration. The cells are designed to drain with no risk of standing water and breeding of mosquitoes.

A rain garden typically does not have the full spectrum of engineered featu bio-retention cells have, such as underdrains and the entire soil mix. They designed and built by homeowners and located near a drainage area, such downspout.

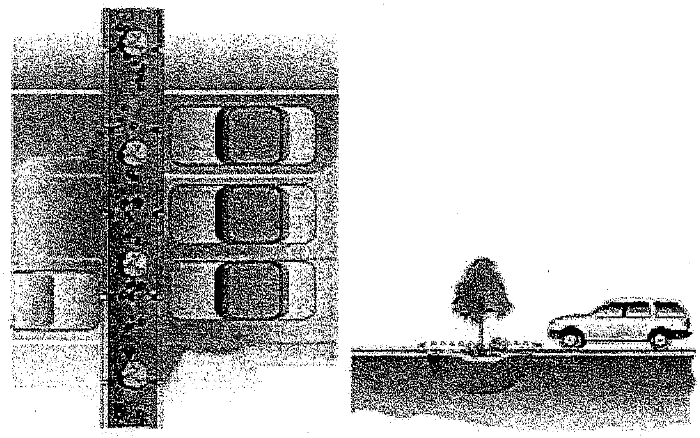


Fig. 19: Bio-retentio
schematic
Courtesy Pierce Cou
Washington and AHE

Typical Uses: Parking lot islands, edges of paved areas (roads or parking l
adjacent to buildings, open space, median strips, swales.

Land Use: Ideal for commercial, industrial, and residential (urban, suburb
urban). They are widely used in transportation projects (highway medians
projects).

They are suitable for new construction and retrofit projects.

Approximate Cost: Residential costs average $3-$4 per square foot of size
excavation and soil amendment costs. Plant materials are comparable to c
landscaping costs.

Commercial, industrial, and institutional site costs can range from $10-$4
square foot, based on the need for control structures, curbing, storm drai
underdrains.

Maintenance: Routine maintenance is required and can be performed as p
regular site landscaping program (i.e., biannual evaluation of trees and sh
regular pruning schedule). The use of native, site-appropriate vegetation r
need for fertilizers, pesticides, excessive water, and overall maintenance
requirements.

Additional Benefits: Easily customized to various projects (size, shape, an
and land uses; enhances aesthetic value of site; uses small parcels of lan
easements, right-of-ways; easily retrofitted into existing buildings/open s

Design Specs and Supplementary Information:

Bayscapes at the U.S. Army Environmental Center
Low Impact Development Center—Bio-retention Specification page
Prince George's County Bio-retention Design Specifications and Criteria
Prince George's County Bio-retention resource page

2) Vegetated Swale (Bio-swale)

A vegetated or grassed swale is an area with dense vegetation that retain: the first flush of runoff from impervious surfaces. It is constructed downst runoff source. After the soil-plant mixture below the channel becomes satı swale acts as a conveyance structure to a bio-retention cell, wetland, or ir area.

There is a range of designs for these systems. Some swales are designed pollutants and promote infiltration and others are designed with a geo-tex that stores the runoff for slow release into depressed open areas or an infi zone.

Alternative Devices; Filter strip or vegetated buffer.

Typical Uses: Edges of paved areas (roads or parking lots), parking lot isla intermediary common spaces, open space, or adjacent to buildings.

Land Use: Commercial, industrial, residential (urban, suburban, ultra-urba transportation projects (highway medians and rail projects); new construc retrofit projects.

Approximate Cost: $0.25 per square foot for construction only; $0.50 per for design and construction.

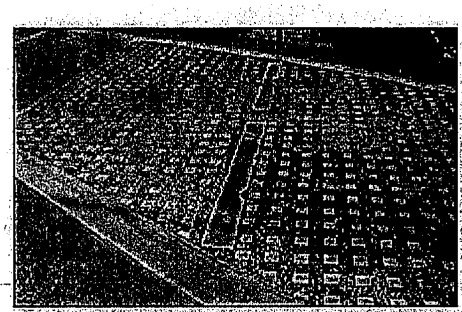
Maintenance: Routine maintenance is required. Maintenance of a dense, h vegetated cover; periodic mowing; weed control; reseeding of bare areas; clearing of debris and accumulated sediment.

Additional Benefits: Easily customized to various projects (size, shape, an and land uses; enhances aesthetic value of site; uses small parcels of lanc easements, right-of-ways; easily retrofitted into existing buildings/open sı

Design Specs and Supplementary Information:

Virginia Dept of Conservation and Recreation Storm Water Management Pı

3) Permeable Pavement



Left: Fig. 20: Belgium block pavers in parking bays
(Photo Credit: The Low Impact Development Center)
Right: Fig. 21: Permeable parking bays
(Courtesy Cahill Associates, Inc.)

Disconnecting impervious areas is a fundamental component of the LID aı

Roofs, sidewalks, and paved surfaces are disconnected from each other to more uniform distribution of runoff into pervious areas. Conveying runoff i vegetated areas keeps the water from directly entering the storm drain ne reduces runoff volume, and promotes distributed infiltration.

Since paved surfaces make up a large portion of the urban (or developed) the use of permeable pavement is very effective at stabilizing the hydrolo of a site. Permeable surfaces can be used in conjunction with subsurface i galleries (subsurface retention facilities) as seen in Section 6.

A secondary benefit of permeable paving is its performance in snowy cond Cahill Associates reports an increase in demand for the installation of pern asphalt in the Northeast as a result of reduced maintenance costs (snow s and desalting) due to rapid snowmelt on permeable surfaces.

Types of permeable pavement include permeable asphalt, permeable conc block pavers, plastic grids, vegetated grids, Belgium block (in photo), turf gravel, cobbles, brick, natural stone, etc.

Typical Uses: Parking bays, parking lanes, sidewalks, roads. Blocks and pc pavement are generally used in high traffic parking and roadway applicati respectively grid systems are more commonly used in auxiliary parking ar roadways.

Land Use: Ideal for commercial, industrial, and residential (urban, suburb urban); suitable for new construction and retrofit projects.

Approximate Cost: Varies according to product. Typically, the cost is highe conventional paving systems; however, they help reduce the overall storm infrastructure costs.

Maintenance: Varies according to product. Routine street sweeping will su infiltration capacity of voids. Porous concrete/asphalt require annual vacu remove accumulated sediment and dirt.

Additional Benefits: Easily customized to various projects and land uses; e aesthetic value of site; easily retrofitted into existing paving configuration

Design Specs and Supplementary Information:

Ford Rouge River Manufacturing Plant (Cahill Associates)
Permeable Paver Specification (Low Impact Development Center)
Porous Asphalt with Subsurface Infiltration/Storage Bed (Cahill Associates
Porous Concrete with Subsurface Infiltration/Storage Bed (Cahill Associate
Toolbase Services (National Association of Home Builders)

4) Subsurface Retention Facilities

Subsurface retention facilities are typically constructed below parking lots permeable or impervious) and can be built to any depth to retain, filter, in alter the runoff volume and timing. This practice is well suited to dense ur Subsurface facilities can provide a considerable amount of runoff storage.

Fig. 22 shows that the porous parking bay has an infiltration gallery (with space) below it for storm water retention. The water is filtered through the aggregate and infiltrates into the ground. An alternative strategy is to con subsurface facility with a filtering and pumping mechanism so that collecte can be reused for non-potable uses such as irrigation or flushing of toilets.

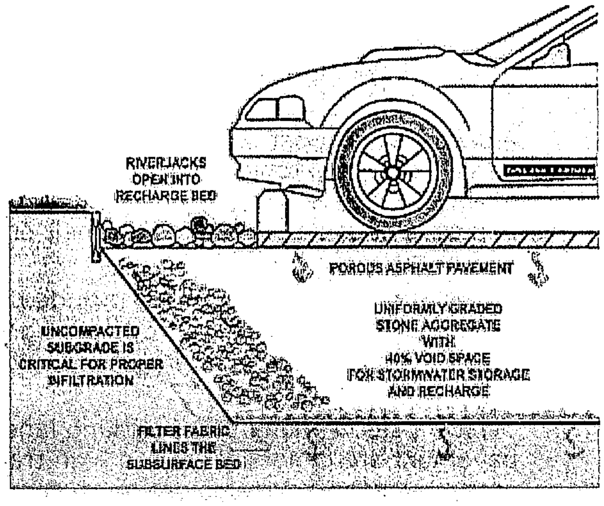


Fig. 22: Cross section of por pavement
Courtesy Cahill Associates, I

Similar techniques include gravel storage galleries, sand filters, infiltration infiltration trenches (for areas with space constraints).

Typical Uses: Parking lots, sidewalks, and roads.

Land Use: Ideal for commercial, industrial, and residential (urban, suburb urban); suitable for new construction and retrofit projects.

Approximate Cost: Costs are typically higher than conventional paving sys however, they help reduce the overall storm water infrastructure costs (la for ponds, cost of pipes, inlets, curbs/gutters).

Maintenance: Varies according to manufacturer; routine street sweeping a vacuuming will retain infiltration capacity of voids.

Additional Benefits: Easily customized to various projects and land uses; e aesthetic value of site; easily retrofitted into existing paving configuration

Design Specs and Supplementary Information: These are specialized syste should be designed by, or under the direct supervision of, an appropriate l professional.

Porous Asphalt with Subsurface Infiltration/Storage Bed (Cahill Associates

The reduction of street widths (i.e., from 36' to 24') can result in a cost sa approximately $70,000 per mile in street infrastructure costs (estimated p = $15 per square yard).

Land Use: Residential, commercial, industrial.

Design Specs and Supplementary Information: Green Cove Basin, Olympia
Washington

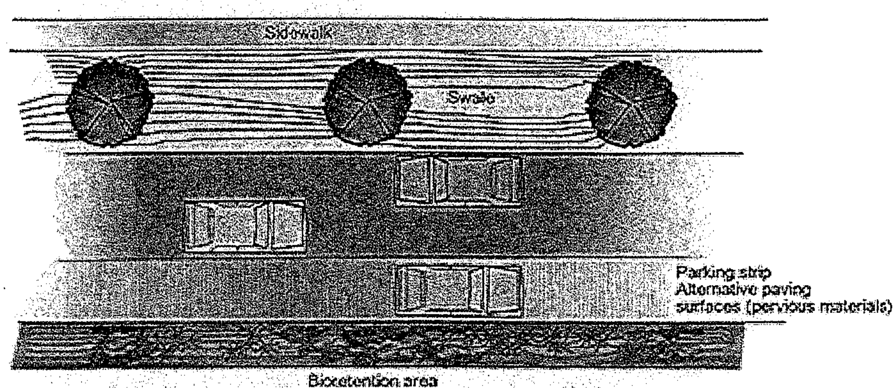


Fig. 23: Reduced road widths and vegetated swales
Courtesy Pierce County, Washington and AHBL, Inc.

5) Tree Box Filter

Tree box filters are essentially 'boxed' bio-retention cells that are placed a (typically where storm drain inlets are positioned). They receive the first fl runoff along the curb and the storm water is filtered through layers of veg soil before it enters a catch basin. Tree box filters also beautify the streets landscape plantings such as street trees, shrubs, ornamental grasses, or p and can be used to improve the appearance of an area or to provide habit

Typical Uses: Positioned along the curb of a street; particularly effective a point source pollution in urban areas by retrofitting/ replacing existing sto

Land Use: Commercial, residential (urban, suburban, ultra-urban), and inc areas.

Approximate Cost: Approximately $6,000 per unit per 1/4 acre of impervi This estimate includes two years of operating maintenance and filter mate plants. Additional costs include installation and annual maintenance. Insta approximately $1,500 per unit (varies with each site).

Maintenance: Tree box filters require more specialized maintenance to ens media is not clogged and there is no accumulation of toxic materials, such metals. Maintenance is typically performed by Departments of Transportat agencies responsible for storm drain maintenance. Annual manufacturer m is $500 per unit; owner maintenance costs are approximately $100 per ur

Additional Benefits: Improves water quality and enhances the community.

Design Specs and Supplementary Information:

Specification of Tree Box Filters (Low Impact Development Center)
Sizing of Tree Box Filters (Low Impact Development Center)
Filterra by Americast
Virginia Storm Water Management Program, Technical Bulleting #6

6) Disconnected Downspouts

Downspouts can be disconnected from underdrains and the runoff directec vegetated areas to reduce runoff volume, promote infiltration, and change timing.

7) Rain Barrels and Cisterns

Rain barrels are placed outside of a building at roof downspouts to collect rooftop runoff for later reuse in lawn and garden watering. They can be us change runoff timing and to reduce runoff volume. Rain barrels have man advantages in urban settings. They take up very little space, are inexpens very easy to install.

Cisterns are larger storage facilities for non-potable use in residential, com industrial applications. They store water in manufactured tanks or undergr storage areas. They can be used with any type of roof structure to interce and reduce runoff volume. The water can be treated and used for domesti fountains, pools, gray water, air conditioning, and other purposes. Both ci rain barrels can be implemented without the use of pumping devices, inste on gravity flow.

Typical Uses: Placed outside of homes or businesses to irrigate landscapin

Land Use: Residential, commercial, industrial.

Approximate Cost: Rain barrels cost approximately $120; the cost of ciste depending on their size, material, location (above or below ground), and v they are prefabricated or constructed on site. They range in volumes from of gallons for residential use to tens of thousands of gallons for commerci industrial use.

Maintenance: Rain barrels require regular maintenance by the home/ busi including draining after rainstorms and removal of leaves and debris collec screens. Cisterns, along with all their components and accessories, should regular inspection at least twice a year.

Design Specs and Supplementary Information:

Rainscapes

8) Site Appropriate Landscaping

When selecting plants for a landscape design, it is important to have know the site conditions. Plant materials should be selected for their form, color texture, as well as solar, soil, and moisture requirements. Plants that do w various micro-climates on a site are considered "site appropriate."

Fig. 24: Native plants thrive in dry cond
Photo Credit: Chesapeake Native Nurse

It is increasingly recommended that native plants (vegetation that grows r particular climates or regions) be used because of their performance, site enhancement, and life-cycle cost benefits. Native plants typically cost mor (depending on local availability); however, they are more cost-effective in run because they require less water and fertilizer, and are more resistant pests and diseases than non-native ornamentals. Life-cycle costs are redu reduced maintenance and replanting requirements. Native plants are also be very effective in managing storm water because many species have de systems which stabilize soil and facilitate the infiltration of storm water ru Additionally, native plants provide habitat for local/regional wildlife.

Care should be taken to not plant invasive species as they tend to crowd c native species. Some common groundcovers, shrubs, and vines are invasi prohibited from being planted. Refer to your state list of invasive plants.

Design Specs and Supplementary Information:

Chesapeake Bay Foundation Bay Friendly Landscaping
Lady Bird Johnson Wildflower Center Native Plant Database
Plant Species Appropriate for Use in Bio-retention Cells (Prince Georges De of Environmental Resources)

9) Other LID Technologies Include:

a. *Green Roofs*—Vegetated rooftops that use a plant-soil complex to st and filter rainfall. They reduce runoff volume and improve runoff tin multilayered systems use a lightweight soil mixture and sedums (no provide energy conservation benefits and aesthetic improvements to They can be used on expansive concrete roof buildings ("big boxes" scale residential roof structures. See WBDG Extensive Green Roofs
b. *Soil Amendments and Aeration*—Soil amendments increase the infilt water storage capabilities to reduce runoff from a site. Additionally, compost, lime, or organic materials alter the physical, chemical, anc characteristics of the soils to improve plant growth. Aeration of the can be done in conjunction with routine mowing activities, can incre storage, infiltration, and pollutant filtering capabilities of grassed are Soil Amendment/Compost Specification (Low Impact Development C
c. *Pollution Prevention Lawn Care*—Proper fertilizer and pesticide appli significantly contribute to lowering nutrients and chemical impairme include fall fertilization to decrease nutrient runoff.

LOW IMPACT DEVELOPMENT TECHNOLOGIES

Refer to *Achieving Sustainable Site Design through Low Impact Developm *Practices* Resource Page for more detailed descriptions about the LID site approach, the site design process, and case studies.

RELEVANT CODES AND STANDARDS

Regulatory Compliance

Chesapeake Bay Agreement 2000
Clean Water Act

- Section 303. Total Maximum Daily Loads
- Section 311. Spill Prevention, Control, and Countermeasure Require
- Section 319. State Non-Point Source Management Program
- Section 401. Certification and Wetlands
- Section 402. National Pollutant Discharge Elimination System (NPDE
- Section 404. Regulation of Dredged or Fill Material

Coastal Zone Management Act
Energy Policy Act of 1992
Estuaries and Clean Waters Act of 2000
National Environmental Policy Act of 1969
Safe Drinking Water Act Wellhead Protection Program
Sikes Act

Federal Directives

Executive Order 13148, "Greening the Government Through Leadership in Environmental Management"
Executive Order 13123, "Greening the Government Through Efficient Ener Management"
Executive Order 13101, "Greening the Government Through Waste Prever Recycling, and Federal Acquisition"

ADDITIONAL RESOURCES

WBDG

Achieving Sustainable Site Design through Low Impact Development Pract Protect and Conserve Water, Life-Cycle Cost Analysis (LCCA), Sustainable, Orders, Extensive Green Roofs.

Associations

National Association of Homebuilders-Low Impact Development Practices f
Water Management

Organizations

Low Impact Development Center, Inc.
Puget Sound Action Team
Sustainable Buildings Industry Council (SBIC)
U.S. Green Buildings Council (USGBC)

Publications

GSA LEED® Applications Guide
GSA LEED® Cost Study
Natural Approaches to Storm Water Management
The Practice of Low Impact Development National Association of Home Bu
(NAHB) for the Dept. of HUD order 1-800-245-2691; helpdesk@huduse
NAHB
"Reducing Combined Sewer Overflows—Toward Clean Water in Washingto
415 KB)
"Out of the Gutter—Reducing Polluted Runoff in the District of Columbia" (
MB) (NRDC)
Low Impact Development
Low Impact Development—Protecting Water Resources as Our Cities Grow
MB)

Design and Analysis Tools

Bioretention Design Software
Bioretention Facility Design References
LID Design Software
Low Impact Development Urban Design Tools
Prince Georges County—Low Impact Development

Training

American Society of Civil Engineers (ASCE) Training
Applied Stormwater Management Design Training
Low Impact Development Conferences
Low Impact Development Conference 2001 (Puget Sound)
Low Impact Development Training Workshops

Other

Environmental Protection Agency (EPA)
EPA—Low Impact Development
EPA—Storm Water Management
EPA—Storm Water Management at the EPA Headquarters Office Complex
National Association of Homebuilders Research Center LID Web Resources

Prince Georges County Other LID Links
Puget Sound Action Team LID Web Resources

Updated: 08-23-2005

Commen

LOW IMPACT DEVELOPMENT

for

BIG BOX RETAILERS

Prepared Under EPA Assistance Agreement # AW-83203101
For EPA Office of Water
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TABLE OF CONTENTS

I. PURPOSE

This effort was funded by an EPA Assistance Agreement funded by the Office of Water. The recommendations or outcomes of this effort may or may not reflect the views or policies of EPA. The purpose of this project is to provide large building and site footprint high volume retailers with strategies that integrate innovative and highly effective Low Impact Development (LID) stormwater management techniques into their site designs for regulatory compliance and natural resource protection at the local levels. LID is an innovative approach to stormwater management that uses decentralized, or source, controls to replicate pre-development hydrology (stormwater) conditions. This approach can be used as an alternative or enhancement for conventional end-of-pipe stormwater pond technology. This alternative tool is important because of the potential to lessen the energy impacts of large concentrated volumes of runoff from conventional end-of-pipe approaches on receiving waters as well as reducing the development footprint and long-term maintenance considerations for end-of-pipe facilities.

The Center has partnered with the Target Corporation for this effort. Target provided input on typical industry planning, design, and operational considerations as well as review for the effort. The focus of the effort is to present these concepts and techniques in an easily understood format so that a dialogue between corporate developers, local engineers, and local governments can be initiated on how to adapt and integrate these strategies and techniques into the local regulatory and watershed protection programs.

II. DOCUMENT ORGANIZATION

The document includes prototypical designs and specifications that can be incorporated into corporate design manuals and design guidance memorandums for use by facility planners, operators, and local design planners and engineers. This includes information on the effectiveness of the practices and ancillary benefits, such as heat island reduction, water conservation, and aesthetics. Information on how to calculate and demonstrate the effectiveness of the practices and in-ground case studies is included. This information can also be used to show the benefits of these practices to municipal officials and stakeholders as part of the local permit process. The document is organized into the following areas:

- *Introduction to LID Strategies and Techniques:* A brief overview of LID is provided. This includes information on LID design strategies and Best Management Practices (BMPs) that are potentially suited for Big Box retailers.
- *LID Design Strategies:* This section includes lists of potential design strategies for large footprint retailers.
- *LID Design Techniques:* The effectiveness and selection of techniques is discussed in this section. This includes information on how the techniques can be used to meet specific water quality objectives.
- *Case Studies:* Typical design situations are presented and discussed.
- *Fact Sheets:* Detailed information on technologies are presented.

III. INTRODUCTION TO LID STRATEGIES AND TECHNIQUES

The following section presents an overview of Low Impact Development (LID) approaches that are appropriate for land development activities. Comprehensive descriptions of LID strategies and design analysis tools are available in print (USEPA, 2002) and on the internet.

III.1. LID Background

Low Impact Development (LID) is a design strategy that utilizes decentralized small-scale source control structural and/or non-structural stormwater practices to meet certain technical requirements of federal, state, and local government stormwater management regulations, as well as natural resource protection and restoration goals. The goal of LID is to maintain or replicate the pre-development hydrologic regime through the use of design techniques to create a functionally equivalent hydrologic site design. Hydrologic functions of storage, infiltration and evaporation, transpiration, ground water recharge, are used to control the volume and frequency of discharges through the use of integrated and distributed micro-scale stormwater practices. This includes structural and non-structural strategies such as retention and detention areas, reduction of impervious surfaces, and the lengthening of flow paths and runoffs time. Other strategies include the preservation/protection of environmentally sensitive site features such as riparian buffers, wetlands, steep slopes, valuable (mature) trees, flood plains, woodlands, and highly permeable soils. LID has also been used to meet targeted regulatory and resource protection objectives. The ability to use "customized" small scale source controls allows the designer to select BMPs that best meet the watershed goals and objectives. This approach also allows for a treatment train approach where there are multiple opportunities to reduce pollutant loads by using a system of different techniques. TLID techniques can also be used to meet ancillary goals such as energy efficiency, community aesthetics, and potential for job training and outreach. Many LID strategies and techniques can be used to achieve Leadership in Energy and Environmental Design (LEED) credits. The LEED program is used by many organizations and communities to certify buildings as being innovative and environmentally responsible.

These controls can be integrated into many common urban land uses on both public and private property to enhance flexibility in siting stormwater controls. This creates the opportunity for partnerships to address construction and maintenance considerations.

This document provides basic templates for an initial candidate set of ten (10) LID BMPs that can be used for Big Box sites. This list was derived by evaluation different Big Box development prototypes to determine which LID BMPs could easily be incorporated into the design without significant alteration of the prototype. The goal of the document is to provide sufficient information on each practice to provide large building and site footprint high volume retailers with strategies to integrate innovative and highly effective LID stormwater management techniques into their site designs. An additional fourteen BMPS are included in Appendix B. These additional BMPs may require significant modification or may not have as an immediate impact as those included in the initial list.

Each candidate BMP listed includes a one-page brief description of the practice as well as an overview consisting of design criteria, advantages/disadvantages, and maintenance. This is followed by a detailed description of information on water quantity/quality controls, location, design and construction materials, cost, maintenance, performance and inspection, potential LEED credits, links to additional information, and issues specific to large building and site footprint high volume retailers.

III.2. Big Box Development Considerations

The "Big Box" store is a relatively new approach to retail. There are numerous configurations and approaches to the planning, design, and construction of these facilities. In many communities the construction of these facilities have significant social and economic implications. They also can have significant hydrologic impacts for the development of the site and for the inertia they can potentially create for the development of surrounding properties. Some of the basic characteristics of Big Box Development can be as follows (adapted from Columbia, 2005):

- The building typically occupies more than 50,000 square feet, with typical ranges between 90,000-200,000 sq. ft.
- Derive their profits from high sales volumes rather than price mark up
- Large windowless, rectangular single-story buildings
- Standardized facades based on corporate standards
- Reliance on auto-borne shoppers
- Highly impervious with large parking and building footprints
- No-frills site development that eschews any community or pedestrian amenities.
- Varying market niches; categories include discount department stores and warehouse clubs

The site design of Big Boxes can be classified by the type of ownership and development of the property they are located on. These are important considerations when determining what are the appropriate site design and water quality protection. This is because the owner/operator of the Big Box may or may not have significant input into the design or selection of the water quality protection strategy based on the timing of their involvement in the project and the overall contribution of the drainage from the facilities. The developments can be classified as follows:

- *Stand Alone Centers:* These facilities are typically developed by the corporation. There is typically significant flexibility in the arrangement of buildings, parking, and infrastructure. This is subject to local codes and requirements for stormwater management, open space, building density, and lot coverage. Utility and physical site opportunities and constraints also apply. Figure One shows a typical Stand Alone Center.

Figure 1 – Stand Alone Center

- *Power Centers:* This is a grouping of several stores and is usually located in a large planned development. The sites are often leased and there is often only minimal input into the overall site design. These centers are often developed over several years and much of the internal road circulation, drainage infrastructure and stormwater management are often in place to accommodate the development "pads" or sites for individual buildings. Figure Two shows a typical PowerCenter.

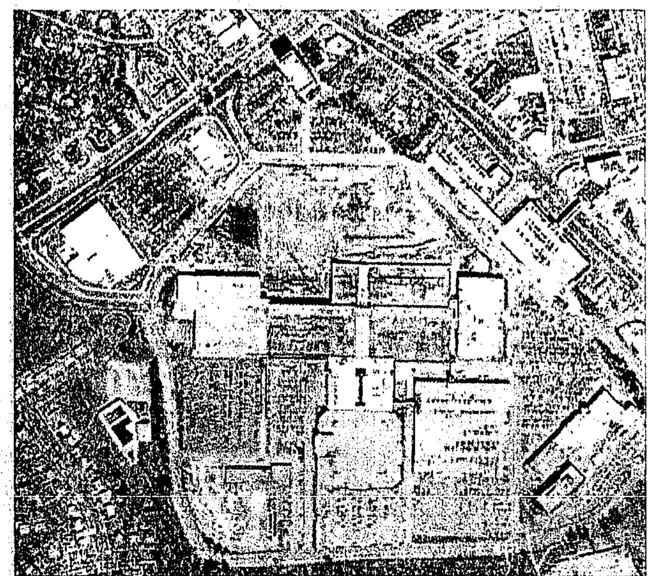


Figure 2 – PowerCenter

- *Infill Development:* These are sites that are located in highly urbanized areas. The buildings are either located in high rise structures at the surface level or built between several buildings and surrounded by streets and alleys. The parking is often in a garage that is shared with other users and there is minimal open space. Figure Three shows a typical Infill Center.

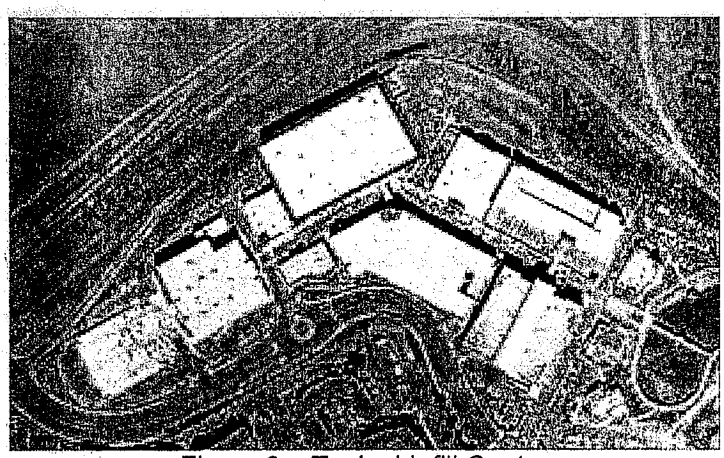


Figure 3 – Typical Infill Center

- *Retrofit:* This is a site where there is an existing building and infrastructure. The building is often torn down and expanded. The site may be repaved and reconstructed to accommodate circulation patterns or stormwater management regulations.

Generally Big Boxes require large impervious areas for parking and vehicular circulation, direct vehicular and pedestrian routes, separated truck loading areas, and large flat roofed building footprints. Most of the designs for these facilities are based on corporate prototypes that are designed to have predictable development costs and circulation patterns that are based on market preferences. This is essential for the successful management of the large-scale rapid construction process that many big box retailers require. The ability for a site to accommodate the basic circulation and infrastructure characteristics are often critical for the decision to build or develop a site. Modifications to the site design templates that are required to meet local codes and ordinances are given careful consideration. These design issues are often handled by a local engineering firm in order to insure the most efficient way to produce the final design and construction permit package.

III.3. Discussion of LID Opportunities for Big Boxes

Many communities have prescriptive stormwater management regulations, where there are specific runoff control rate and volume and water quality management requirements. These are often based on end-of-pipe controls for each development. In these situations the LID approach must be negotiated with the local government. The use of alternative designs are often administratively approved by waivers or modifications to the requirements. The advantages of using LID for the developer include, but are not limited to reducing the visual impact of large scale stormwater management facilities, have additional development area through the elimination of an end-of-pipe pond, utilize the landscape to provide stormwater management and reduce development costs, reduced stormwater utility fees by providing additional water quality.

Many communities are moving towards performance based standards. These can be as complex as limiting concentrations of runoff or reducing runoff volumes. LID can be used to meet these requirements by providing strategies and techniques with predictable removal efficiencies or reductions in runoff volume at the source.

In many instances, there is the requirement for additional or negotiated controls for reduction of the large-scale hydrologic and hydraulic impacts of the development. When there is the need for enhanced water quality, such as when impacts to wetlands or Waters of the U.S. occur, LID techniques can be used to meet the negotiated regulatory requirements. In large planned developments or in zoning categories where there may be the requirements for enhanced site design or environmental controls LID can be used to provide additional landscaping, visual amenities, and water quality enhancements.

III.4. LID Design Approach

The goal of LID site design is to reduce the hydrologic impact of development and to incorporate techniques that maintain or restore the site's hydrologic and hydraulic functions. The optimal LID site design minimizes runoff volume and preserves existing flow paths. This minimizes infrastructural requirements. By contrast, in conventional site design, runoff volume and energy may increase, which results in concentrated flows that require larger and more extensive stormwater infrastructure.

The requirement for efficient access and circulation is critical to the success of the Big Box development. The design elements can be broken down into *Circulation and Customer Parking, Loading Areas,* and *Building Zones.* LID techniques can be incorporated into each of these areas. Some basic design concepts and recommendations include:

- *Circulation and Customer Parking.* These are areas in the front of the building. There is usually a main drive that feeds to the parking areas. The main drive is typically located in the center of the parking lot where possible. Its function is to provide rapid access to parking and loading that is located near the entrance to the building, distribute cares to the remainder of the parking lot, and provide stacking of vehicles at the entrance to the site. There is usually green space or islands that are located on the sides of these areas to provide stacking and accommodate turning movements to the parking isles. These are often landscaped to visually enforce movements. The parking area is sized to accommodate large numbers of vehicles that are present during peak hours and holiday seasons. A significant amount of the parking area may be under utilized during most of the year, but is critical during peak seasons. Most local codes and ordinances require internal and peripheral green space for parking.

- *Loading Areas.* These areas are often located at the rear of the sides of the building. They are often screened or not visible to the building entrance or parking. The loading areas require large open unobstructed pavement areas in order to accommodate truck turning movements and trailer storage. These areas can potentially have high pollutant loads due to the number of truck visits. Employee parking may also be located in or near these areas at the rear of the store.

- *Building Zones.* This is the building and the area immediately adjacent to the building. There is usually a sidewalk immediately in front of the building. It must be wide enough to provide a safe buffer between the building and front loading/drop off area. Cart storage may also be in these areas. This area is usually minimized in order to help move people quickly into the stores. The building itself typically is constructed with a lightweight flat steel structure. The roof drains are usually connected by piping that is hung on the rafters and connected to the site storm drainage system.

III.4.1. LID Planning and Design Objectives

The following are lists of the critical planning and design objectives that can be achieved by using some basic LID that can be incorporated into the planning and design process. Each principle includes a brief description of the key concepts or elements. This list is to be used as a basic design checklist or talking points for planners and designers to communicate the critical elements with building code and planning officials, public officials, and local designers.

LID Planning

These are some basic overall LID principles that are essential for community development and watershed issues.

LID Site Design:

- reduces the impacts of development with site-appropriate, ecologically sensitive technologies,
- achieves stormwater management goals,
- creates more livable places to shop, relax, and recreate. Interesting pavement patterns and landscapes can create successful public spaces.

LID decentralized strategies and techniques are:

- customizable to meet a wide range of stormwater management objectives,
- adaptable to the physical constraints of commercial or mixed-use sites.

Integrating LID controls into site design:

- reduces the impact that development has on the hydrologic water balance,
- restores or maintains the equilibrium of the natural systems,
- reduce the need for extensive stormwater conveyance infrastructure.

Site Design Elements

The following are some of the basic site design criteria that LID strategies and techniques can be used to achieve.

Stormwater Management Objectives

Use LID stormwater controls to meet compliance goals, as well as these stormwater management objectives:

- Runoff Volume Reduction
- Peak Discharge Rate Reduction
- Water Quality Improvement – remove pollutants, reduce sediment/nutrient loads, etc.

Site Functions

- *Operations* - Reduce infrastructure maintenance requirements
- *Circulation* - Visually reinforce or provide a physical framework for vehicular and pedestrian circulation
- *Curb Appeal* - Off-site visibility, marketing, public relations

Corporate and Community Development

Use LID stormwater controls to achieve these corporate programming goals and to provide ancillary community enhancement benefits:

- *"Open Space/Park Design"* – create park-like open space, promenades, etc.,
- *Beautification/Aesthetics* – create "groves," garden-like areas, etc...
- *Afforestation/Reforestation* – urban forest or park-like open space ("green infrastructure")
- *Green Building* – promote green building strategies (i.e., LEED: use of recycled materials, low VOC materials, certified woods, etc.)
- *Water Conservation/Energy Conservation* –promote conservation of natural resources (water) or use of on-site renewable energy (solar, wind, etc.)
- *Public Education* – increase community awareness of conservation and ecological stewardship.

LID Site Design Components

The following is a list of the opportunities and constraints that will effect the selection of LID strategies and techniques.

Site Conditions

Suitability of LID technologies to meet stormwater objectives depends on site conditions, including:

- Soil (i.e., infiltration capacity, degree of compaction)
- Groundwater table
- Topography / Slope
- Available open space (vegetated areas)
- Vertical location of sewers and utilities
- Solar heat
- Wind patterns
- Climate and annual rainfall

Planning Codes and Ordinances

Local master plans, municipal regulations, planning codes and ordinances dictate suitability of LID technologies, including:

- Development Regulations (Zoning, Site Development, Environmental, Critical Areas, Forestry, etc.)
- Construction and Infrastructure Regulations
- Site Development and Stormwater Drainage Regulations
- Design Standards and Guidance
- Comprehensive Planning Documents
- Planning and Land Services Fees
- Reductions in Impact or Utility Fees

III.4.2. LID Design Strategies and Techniques

In order to achieve these objectives site and building design strategies for these elements must be developed. This includes a combination of site design strategies in combination with non-structural and structural BMP techniques. The use of site design strategies will reduce the hydrologic and hydraulic impacts and reduce the need for BMPs. Some basic site design strategies include:

1. **Disconnect Impervious Areas/Downspout Disconnection**
   Runoff from connected impervious surfaces commonly flows directly to a stormwater collection system with no possibility for infiltration into the soil. Highly efficient drainage systems contribute significantly change watershed timing and increase the peak runoff rate and energy that results from the development. For example, roofs and sidewalks commonly drain onto roads, and the runoff is conveyed by the roadway curb and gutter to the nearest storm inlet. Runoff from numerous impervious drainage areas may converge, combining their volumes, peak runoff rates, and pollutant loads. Disconnection decouples roof leaders, roadways and other impervious areas from stormwater conveyance systems, allowing runoff to be collected and managed on site or dispersed into the landscape. Runoff is redirected onto pervious surfaces such as vegetated areas, reducing the amount of directly connected impervious area and potentially reducing the runoff volume and filtering out pollutants.

2. **Site Minimization/Fingerprinting/Impervious Areas Reduction**
   Site fingerprinting, also known as minimal disturbance techniques, is a practice that minimizes ground disturbance by identifying the smallest possible land area that can practically be impacted during site development. Minimizing the amount of site clearing and grading reduces the overall hydrologic impacts of site development. Ground disturbance is typically confined to areas where structures, roads, and rights-of-way will exist after construction is complete. Development is also placed away from environmentally sensitive areas, future open space, tree save areas, future restoration areas, and temporary and permanent vegetative forest buffer zones. Existing vegetated or open space may be preserved instead of clearing a portion of the site in order to create lawn areas.

   A key component of minimizing overall site impacts is reducing impervious areas (both connected and disconnected). Typical techniques include limiting roadway lengths and widths, minimizing lot setbacks (which in turn minimize driveway lengths), installing sidewalks on only one side of private roadways, and by using alternative materials such as permeable paving blocks or porous pavements.

3. **Time of Concentration Practices/Surface Roughening**
   Time of concentration (t_c) practices, such as surface roughening, increase the time it takes for runoff to flow across a site to the drainage point or a BMP. Slowing runoff velocity potentially reduces erosion and increases the potential for infiltration. Increasing t_c is also directly related to the disconnection of impervious areas.

4. **Pollution Prevention**
   Pollution Prevention (P2) is a general term for any activity or management action that reduces or eliminates pollutants before they are propagated downstream. The goal of P2 is to incorporate programs and techniques to keep nonpoint source (NPS) pollutants out of

runoff. This helps to reduce pollutant loads entering BMPs, which enhances their performance and improves their longevity. Reduction of fertilizer, pesticide, and herbicide use and the implementation of regular street sweeping are some common P2 activities. P2 may also involve behavioral changes, such as keeping dumpster lids closed.

III.5. LID BMP Selection Criteria

Selection and sizing of BMPs depends upon a wide range of factors, including control objectives, receiving water quality, water quality parameters of interest, local (as well as federal) legislation. The importance of any of the criteria will vary from location to location, and affect the relative evaluation of overall water quality impacts projected for a big box retail location. Comprehensive selection of a BMP for use on a site depends upon:

- ability to meet regulatory requirements,
- projected system performance (pollutant removal effectiveness),
- public acceptance of the BMP,
- ability to be implemented (relative design constraints),
- institutional constraints,
- associated cost.

Proper BMP selection includes the assessment of the types of constituents found in the stormwater in order to determine the proper unit processes the BMP should employ in order to treat for those pollutants. However, it is also important to identify the sources and land areas contributing the additional stormwater volume and/or excessive loading of pollutants in order to identify source control measures, alternative development practices, and to determine BMP design and maintenance characteristics based upon identification of various land management and land use situations.

Generally, the addition of impervious area as a result of increased development leads to an increase in stormwater runoff volume, higher peak flows, higher average temperature of runoff, collection of a larger mass of pollutants (due to lack of infiltration capacity), and an increased flooding hazard for downstream waterways (Minton 2002, Lee 2002, Novotny 2003). Some impervious areas may be indirectly connected to the site drainage system by sheet flow over pervious and impervious surfaces for eventual discharge into gutters, catch basins, etc., while other areas may flow directly into the drainage system, such as roadways and roofs with attached roof drains.

Minimization of disconnected impervious area (DCIA) can be incorporated both into new design and retrofit scenarios. The use of LID practices for new development, such as porous pavement, planter strips, and eco-roofs, all minimize impervious areas on a site, thus allowing for reduced flow rates, increased infiltration, evapotranspiration (ET), and groundwater recharge rates and therefore a reduction in the pollutant load reaching a BMP system and receiving water body. Retrofit practices, such as the disconnection or relocation of roof drains, may be possible in some older development areas, specifically low density commercial areas (Urbonas and Stahre 1993). Disconnection and relocation of roof downspouts to pervious areas allows runoff to discharge first into grass for infiltration instead of directly into the sewer system or onto the pavement or roadway area (Urbonas and Stahre 1993). This practice is not a panacea, however, since concerns over possible groundwater contamination and localized drainage problems must be addressed.

The following is a "tool box" of LID BMPs that can be incorporated into development guidance manuals. The BMPs listed below were selected because of current industry interest and knowledge of the practice that is currently being used by large-scale Big Box developments. Because of the potentially large number of LID BMPs, including modifications and variations, it is important to develop this framework so that industry and plan reviewers can determine the most appropriate technologies for each land use.

The following table provides a list of ten tools useful to large building and site footprint high volume retailers. Complete fact sheets are provided in Appendix C for each of the ten LID BMPs listed below in Table 1.

Table 1 - LID BMPS

1	Bioretention Basins (Peak and Volume)
2	Bioretention Cells (Water Quality Only)
3	Bioretention Slopes
4	Bioretention Swales
5	Water Quality Swales
6	Permeable/ Porous Pavements (Asphalt, Concrete, Blocks)
7	Tree Box Filters
8	Planter Boxes
9	Cisterns/ Rain Barrels
10	Green Roofs

The function and use of these BMP must be considered in order to use them effectively. The following tables provide a potential listing and classification of the BMPs found in the appendices. The purpose of these lists is to provide an example of the development general criteria and guidance for the selection and use of the BMPS. These are not rigid lists or classifications, but are meant to demonstrate how the BMPs can be matched up to the most appropriate use. More detailed information on the unit processes and overall use can be found in decentralized stormwater guidance documents (WERF 2006). LID stormwater controls can be classified into two different *land development* types, new development and retrofit. Table 2 shows where LID practices can potentially be incorporated into the site design. Table 3 is a representative classification scheme Table 4 categorizes these BMPs into Power Center or stand alone uses. Table 5 demonstrates the effectiveness at meeting stormwater management objectives. Table 6 shows the BMP function and unit process.

Table 2 - Potential LID BMP Locations

BMP	Circulation and Parking	Building	Loading
Cisterns		x	
Conservation (Vegetation)	x		
Downspout Disconnection		x	
Filter Strips	x		
Infiltration Beds/Trenches or Dry Wells	x		
Pocket Wetlands			
Porous Pavement	x		
Rain Gardens	x		x
Reforestation (Vegetation)	x		
Sand Filters	x		x
Soil Amendments	x		
Vegetated Roof		x	
Water Conservation		x	
Pollution Prevention			x
Tree Box Filters	x		x
Bioretention Slopes	x		x

Table 3 - Suitability of BMPs for Land Development Types

BMP	New Development	Retrofit
Cisterns	●	●
Conservation (Vegetation)	●	○
Downspout Disconnection	○	●
Filter Strips	●	●
Infiltration Beds/Trenches or Dry Wells	●	⦿
Pocket Wetlands	●	●
Porous Pavement	●	⦿
Rain Gardens	●	●
Reforestation (Vegetation)	●	●
Sand Filters	●	●
Soil Amendments	●	●
Tree Box Filters	●	●
Vegetated-Roofs	●	●
Vegetated Swales	●	●

Key: ● Highly Suitable ⦿ Moderately Suitable ○ Not Suitable

Table 4 - Suitability of BMPs for Site Layout Types

BMP	"Power Centers"	Stand-Alone
Cisterns	●	●
Conservation (Vegetation)	●	○
Downspout Disconnection	○	○
Filter Strips	●	●
Infiltration Beds/Trenches or Dry Wells	●	●
Pocket Wetlands	●	●
Porous Pavement	●	●
Rain Gardens	●	●
Reforestation (Vegetation)	●	●
Sand Filters	●	●
Soil Amendments	●	●
Tree Box Filters	●	●
Vegetated Roofs	●	●
Vegetated Swales	●	●

Key: ● Highly Suitable ◉ Moderately Suitable ○ Not Suitable

Table 5 - Effectiveness of BMPs in Meeting Stormwater Management Objectives

BMP	Volume	Peak Discharge	Water Quality
Catch Basin Sump/Vault Filters	○		○
Downspout Disconnection	◉	◉	◉
Filter Strips	○	○	◉
Infiltration Practices	◉	○	◉
Pocket Wetlands	●	●	●
Porous Pavement	●	●	◉
Rain Barrels/Cisterns*	◉	○	○
Rain Gardens	●	●	●
Sand Filters	○	○	◉
Soil Amendments	◉	◉	◉
Tree Box Filters	◉	◉	●
Vegetated Roofs	◉	●	●
Vegetated Swales	◉	◉	●

Table 6 - Functional Classification

BMP	Volume Reduction	Peak Discharge	Water Quality	Source Control	Treatment Train	Design Storm
Cisterns	●	●	●	●	●	●
Conservation (Vegetation)	●	●	●	●	●	●
Downspout	○	○	●	●	●	●

Disconnection						
Filter Strips	●	●	●	●	●	●
Infiltration Beds/Trenches or Dry Wells	●	●	●	●	●	●
Pocket Wetlands	●	●	●	●	●	●
Porous Pavement	●	●	●	●	●	●
Rain Gardens	●	●	●	●	●	●
Reforestation (Vegetation)	●	●	●	●	●	●
Sand Filters	●	●	●	●	●	●
Soil Amendments	●	●	●	●	●	●
Tree Box Filters	●	●	●	●	●	●
Vegetated Roofs	●	●	●	●	●	●
Vegetated Swales	●	●	●	●	●	●

IV. LID CASE STUDIES

The following three case studies illustrate potential scenarios where Low Impact Development LID could be used to address stormwater quality and quantity management objectives. Each scenario presents a different development or redevelopment opportunity. The objective is to use the case studies to initiate a dialogue on the potential use and issues that need to be addressed in the location, design and review process and long-term administration and maintenance. The case studies do not present the entire range of possibilities or options. These are not to be viewed as comprehensive or complete drainage calculations and site plans, but are to be used to illustrate the concepts and feasibility of the approach. General assumptions on drainage areas, drainage characteristics topography, soils, land use, and other conditions that would potentially affect the hydrologic response of the site are used. A brief description of each case study is listed below.

Case Study One: Big Box Retail
This is a stand alone Big Box Store. These sites typically are large scale changes to the land use that results in large connected impervious areas. The concept design illustrates how to disconnect and distribute the drainage into smaller management facilities to meet water quality and stormwater quantity objectives.

Summary:

- Determine feasibility for water quality control and for providing storage volume to limit the 10-yr, 24-hr peak discharge rate to the pre-development condition.

- Use NRCS TR-55 graphical peak discharge method to determine storage volume.
- Drainage area is assumed to equal site area, 22.5 ac.

Existing Conditions

- Site is sloping from SE to NW at 2 to 5 percent.
- Moderate slope on western portion of side.
- 0.7 acres Woods and 21.8 Meadows.
- HSG C. Weighted CN is 65.
- Tc is 0.27 hours.
- Peak Discharge (CFS): 41.
- Runoff Volume (in.): 1.79.

Post-Development Conditions

- Afforestation and soil amendments on western portion of site. Increase infiltration capacity to HSG B and change in land cover.
- Conservation of woods.
- Credit bioretention areas as HSG B and Meadow.
- Weighted CN is 86.
- T_c is 0.25 hours.
- Peak Discharge (CFS): 92.
- Runoff Volume (in.): 3.65.

Results

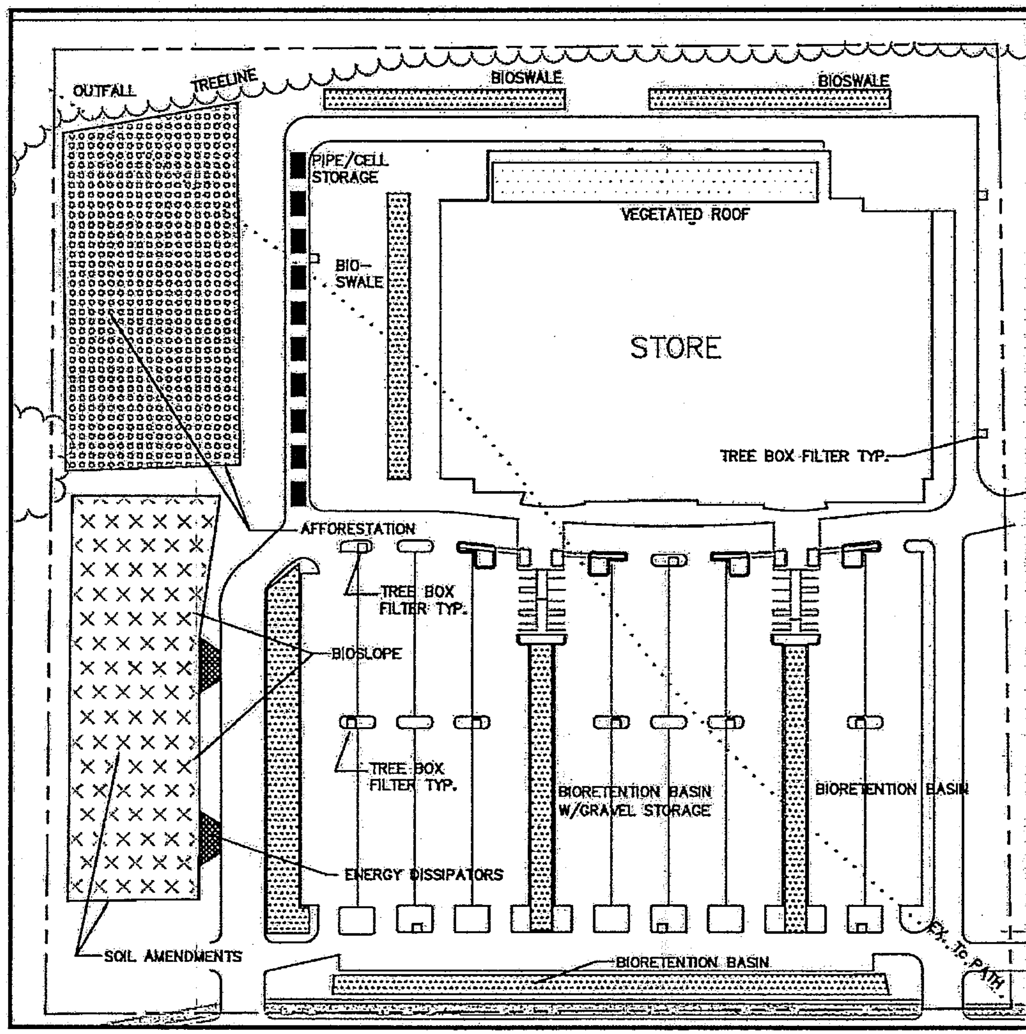
- Detention volume: 2.1 acre feet or 1.1 inches using TR-55 graphical peak method.

BMPs

- Tree box filters provide majority of water quality control
- Green roof captures first 1" of roof runoff.
- Bioretention basins: 1.7 ac/ft storage is available.
    - Assume 6" surface storage and 1' subsurface storage is provided.
- Some bioretention basins include additional gravel underground storage.
    - 0.35 ac/ft is available in gravel storage.
- Some runoff is treated by soil amendment / bioslope areas.
- Pipes or other underground facilities provide 0.5 ac/ft storage.
- Additional storage can be provided in bioswales, amended soils, or cisterns.

Note

- See concept design on the next page.



Case Study Four: Big Box Development

- Determine feasibility for water quality control and for providing storage volume to limit the 10-yr, 24-hr peak discharge rate to the pre-development condition.
- Use NRCS TR-55 graphical peak discharge method to determine storage volume.
- Drainage area is assumed to equal site area, 22.5 ac.

Existing Conditions

- Site is sloping from SE to NW at 2 to 5 percent
- Moderate slope on western portion of site
- 0.7 acres Woods and 21.8 acres Meadow
- HSG C. Weighted CN is 65
- Tc is 0.27 hours
- Peak Discharge (cfs): 41
- Runoff Volume (in.): 1.79

Post-Development Conditions

- Afforestation and soil amendments on western portion of site. Increase infiltration capacity to HSG B and change in land cover
- Conservation of woods
- Credit bioretention areas as HSG B and Meadow
- Weighted CN is 86
- Tc is 0.26 hours
- Peak Discharge (cfs): 92
- Runoff Volume (in.): 3.65

Results

- Detention volume: 2.1 acre feet or 1.1 inches using TR-55 graphical peak method

BMPs

- Tree box filters provide majority of water quality control
- Green roof captures first 1" of roof runoff (Water quality volume = first 0.5" of roof runoff.)
- Bioretention basins: 1.7 ac/ft storage is available.
    - Assume 6" surface storage and 1' subsurface storage is provided.
- Some bioretention basins include additional gravel underground storage.
    - 0.35 ac/ft is available in gravel storage.
- Some runoff is treated by soil amendment / bioslope areas
- Pipes or other underground facilites provide 0.5 ac/ft storage
- Additional storage can be provided in bioswales, amended soils, or cisterns.

CASE STUDY
BIG BOX RETAIL SITE

LOW IMPACT DEVELOPMENT CASE STUDY
OCTOBER 2005

A008108

Case Study Two: Commercial Infill

This case study illustrates the potential for the retrofit of an existing strip shopping center with water quality management practices as part of a redevelopment plan. The redevelopment includes a drive through fast-food facility and a new retail strip. Stormwater quantity and quality control are provided for these areas. Retrofit of the existing impervious areas with water quality controls is also shown.

Summary:

The total site area is 20.5 acres. An existing strip mall is located on the eastern 14.75 acres.

The western 5.75 acres is being developed as a fast food drive through and small strip retail shops.

For the western 5.75 acres, demonstrate how to provide storage for the water quality volume (WQV) and to provide detention to limit the 10-yr, 2-hr peak discharge rate to the pre-development condition.

For the eastern 14.75 acres, add BMPs to provide water quality improvements and reduce runoff volume.

Assume that providing storage for 3" of runoff from the post-development impervious area will provide required detention storage for the 10-yr, 2-hr storm.

Existing Conditions

- The site drains from northeast to southwest. Slopes are from 2 to 3 percent.
- The eastern section has 8.9 acres of impervious area.
- The western section is undeveloped.

Post-Development Conditions

- The western section has 3.4 acres of impervious area.
- Soil amendments are added to 0.66 acres in the western section, increasing the area's infiltration capacity.
- 2.9 acres across the entire site are afforested.

Result – New Development

- Water quality volume = 6,200 C.F.
  - WQV = 0.5" / (12" per foot) * 3.4 acres* (43,560 S.F. per acre)
- Detention volume = 37,000 C.F.
  - Detention volume = 3" / (12" per foot) * 3.4 acres* (43,560 S.F. per acre)
- WQV is contained within the detention volume; therefore BMPs will be sized to contain the detention volume.

BMPs – New Development

- Use a combination of bioretention basins, bioswales, permeable pavement, and green roof.
- Bioretention basins and bioswales are designed so that surface ponding drains within 24 hours.
- BMPs are sized to collectively capture 3" of runoff from the post-development impervious area.

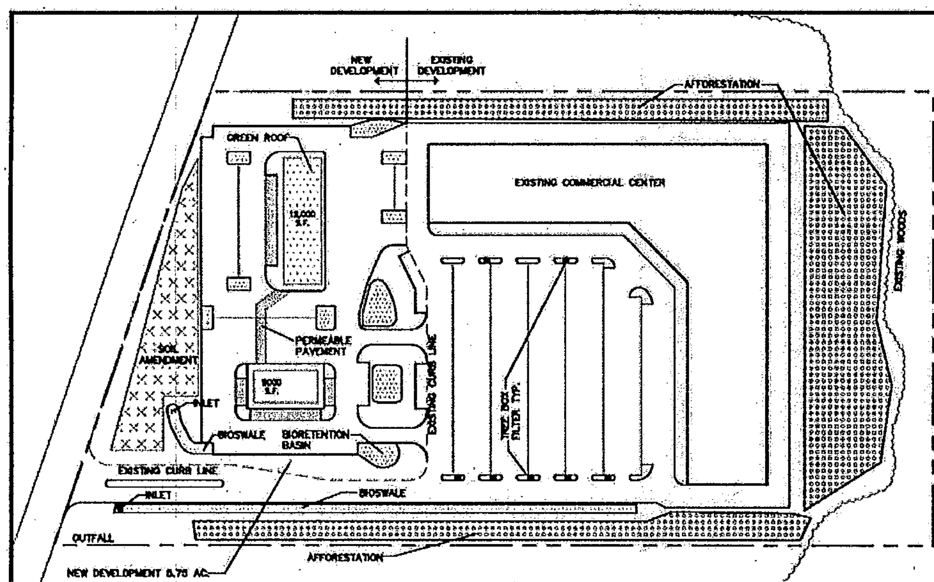
- One 11,000 S.F. green roof.
  - Covers entire 12, 000 S.F. roof of strip retail shops except utility areas and access points.
  - Assume 1.5' storage within green roof media and no ponding.
  - Additional storage for roof runoff is provided in adjacent BMPs.
- Ten bioretention basins and one bioswale totaling 15,800 S.F.
  - Capture runoff from parking lot and both roofs.
  - Assume 6" surface storage and 1" subsurface storage is provided.
  - Paved areas are graded to drain to the nearest bioretention basin (or bioswale).
- Five section of permeable pavement totaling 8,000 S.F.
  - Capture Runoff from parking lots.
  - Assume 1.5" storage in gravel bed below permeable pavement.

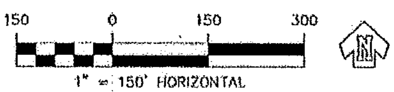
BMPs – Remainder of Site (Existing Development)

- One 10,600 S.F. bioswale with yard inlet.
  - Capture runoff from existing roadway to improve water quality.
  - Assume 6" surface storage and 6" subsurface storage is provided.
  - Bioswale is 820' long and 13" wide.
  - Can also provide conveyance for larger storms.
- Tree box filters provide water quality improvements for existing parking area in eastern section.

Note

- See concept design on the next page.





__Case Study Three: Existing Commercial Development Retrofit__

- The total site area is 20.5 acres. An existing strip mall is located on the eastern 14.75 acres.
- The western 5.75 acres is being developed as a fast food drive through and small strip retail shops.
- For the western 5.75 acres, demonstrate how to provide storage for the water quality volume (WQV) and to provide detention to limit the 10-yr, 2-hr peak discharge rate to the pre-development condition.
- For the eastern 14.75 acres, add BMPs to provide water quality improvements and reduce runoff volume.
- Assume that providing storage for 3" of runoff from the post-development impervious area will provide required detention storage for the 10-yr, 2-hr storm.
- WQV = 0.5" of runoff over the impervious area.
- Assume drainage area for western section is limited to the 5.75 acres in that section (no offsite runoff, or runoff from the eastern section)

__Existing Conditions__

- The site drains from northeast to southwest. Slopes are from 2 to 3 percent.
- The eastern section has 8.9 acres of impervious area.
- The western section is undeveloped.

__Post-Development Conditions__

- The western section has 3.4 acres of impervious area.
- Soil amendments are added to 0.66 acres in the western section, increasing the area's infiltration capacity.
- 2.9 acres across the entire site are afforested.

__Result – New Development__

- Water quality volume = 6,200 C.F.
  - o WQV = 0.5" / (12" per foot) * 3.4 acres * (43,560 S.F. per acre)
- Detention volume = 37,000 C.F.
  - o Detention volume = 3" / (12" per foot) * 3.4 acres * (43,560 S.F. per acre)
- WQV is contained within the detention volume; therefore, BMPs will be sized to contain the detention volume.

__BMPs – New Development__

- Use a combination of bioretention basins, bioswales, permeable pavement, and green roof.
- Bioretention basins and bioswales are designed so that surface ponding drains within 24 hours.
- BMPs are sized to collectively capture 3" of runoff from the post-development impervious area.
- One (1) 11,000 S.F. green roof
  - o Covers entire 12,000 S.F. roof of strip retail shops except utility areas and access points.
  - o Assume 1.5" storage within green roof media and no ponding.
  - o Additional storage for roof runoff is provided in adjacent BMPs.

__BMPs – New Development (Continued)__

- Ten (10) bioretention basins and one (1) bioswale totaling 15,800 S.F.
  - o Capture runoff from parking lot and both roofs
  - o Assume 6" surface storage and 1' subsurface storage is provided.
  - o Paved areas are graded to drain to the nearest bioretention basin (or bioswale).
- Five (5) sections of permeable pavement totaling 8,000 S.F.
  - o Capture runoff from parking lots
  - o Assume 1.5' storage in gravel bed below permeable pavement.

__BMPs – Remainder of Site (Existing Development)__

- One (1) 10,800 S.F. bioswale with yard inlet
  - o Capture runoff from existing roadway to improve water quality
  - o Assume 6" surface storage and 6" subsurface storage is provided.
  - o Bioswale is 820' long and 13' wide.
  - o Can also provide conveyance for larger storms.
- Tree box filters provide water quality improvements for existing parking area in eastern section.

CASE STUDY
EXISTING COMMERCIAL DEVELOPMENT
RETROFIT

LOW IMPACT DEVELOPMENT CASE STUDY
OCTOBER 2005

Case Study Three: Big Box Site Development

This case study illustrates the affects of minor changes in layout at a Super Center using LID. The following shows LID storage capacity as well as volume reduction for both a 2-year 24-hour storm event and a 10-year 24-hour storm event. These retrofits use decentralized LID methods to disconnect stormwater from a centralized stormwater system and runoff. LID practices reduce stormwater peak and volume flow while improving the water quality of the runoff.

Summary:

- Determine feasibility for water quality control and for providing storage volume to limit the 10-yr, 24-hr peak discharge rate to the pre-development condition.
- Use NRCS TR-55 graphical peak discharge method to determine storage volume.
- Drainage area is assumed to equal site area, 91 ac.
- Assume 85% imperious cover and a CN of 95
- Runoff using NRCS TR-55 graphical peak discharge method for the 2-year and 10-year Type II storm is 20 ac-ft and 34ac-ft, respectively.

Retrofit Conditions:

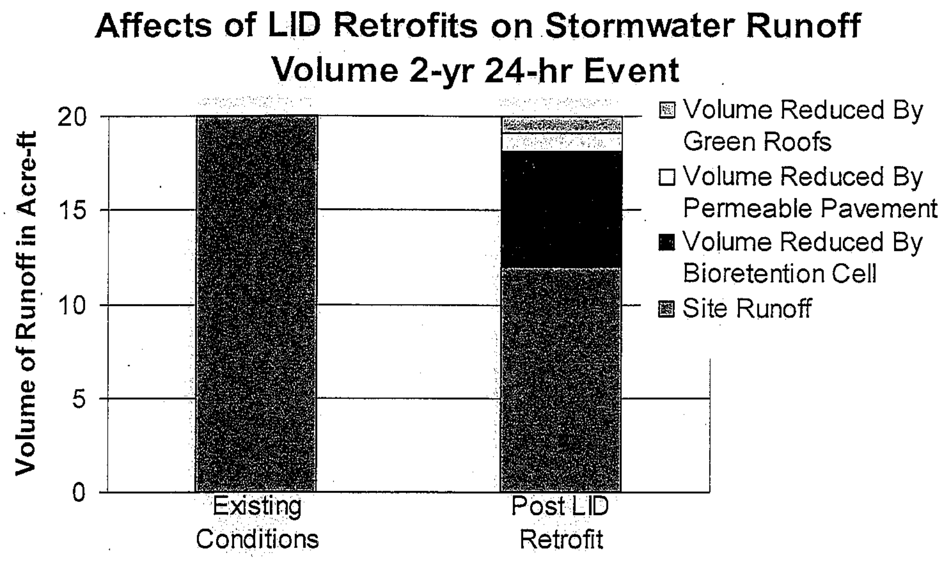
- 2.2 acres of afforestation on western portion of site. Increase infiltration capacity and change in land cover
- Conservation of woods
- Credit bioretention, permeable pavement, and green roofs areas as HSG B and Open Space

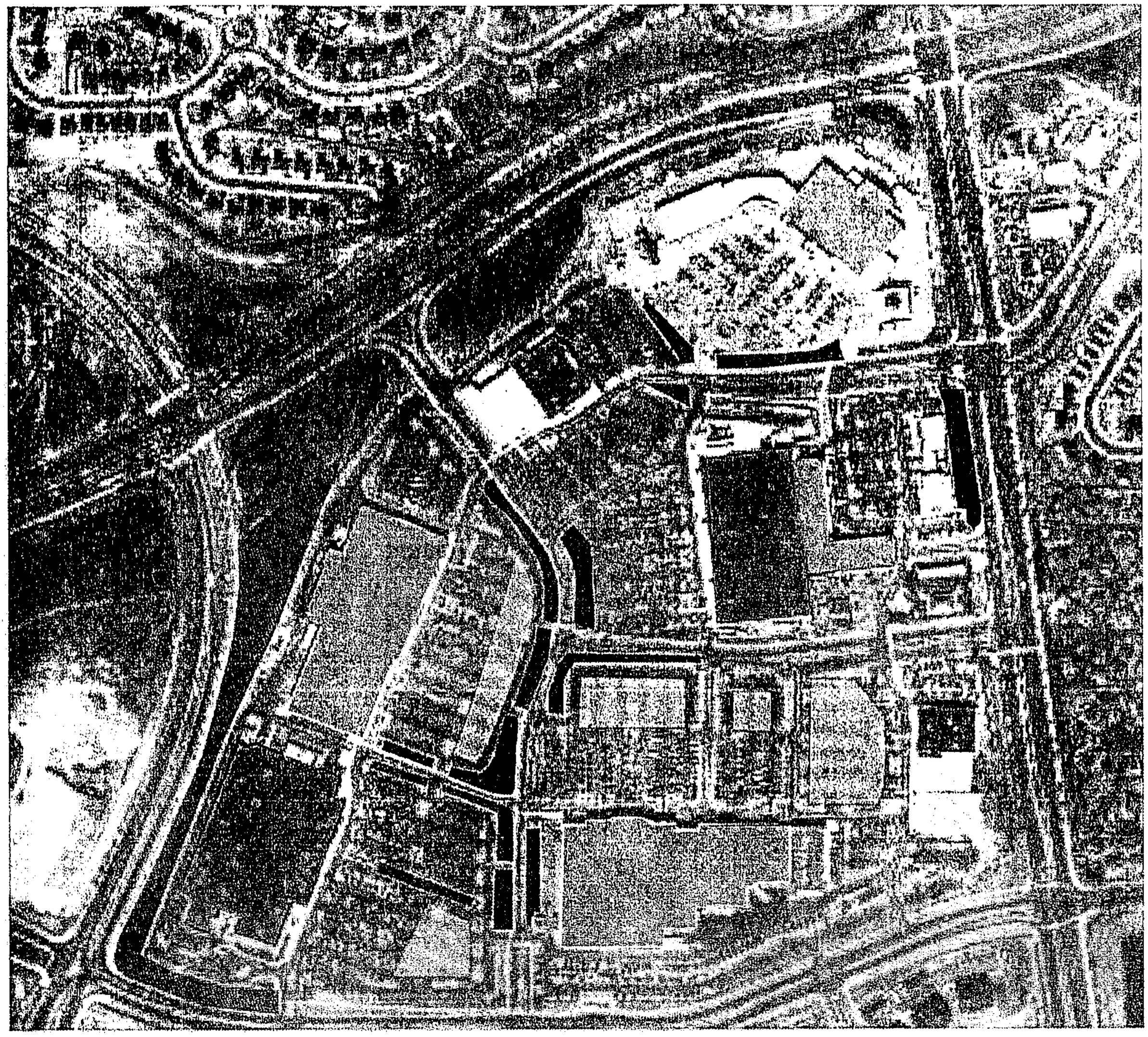
Results:

- Detention volume: 8 acre feet
- Green roofs reduce runoff volume by 17% for a 2 yr. 24 hr. storm and 9.5% for a 10 yr. 24 hr. storm.
- Green roofs, bioretention, and permeable pavers combine to offer benefits of a 23% for a 2 yr. 24 hr. storm and 15% for a 10 yr. 24 hr. storm.

BMPs:

- Green roof captures first 1" of roof runoff, 0.89 ac/ft of storage (Water quality volume = first 0.5" of roof runoff.)
- Bioretention basins: 6.1 ac/ft storage is available.
    - Assume 1' surface storage and 2.5' subsurface storage with a porosity of 0.3.
- Permeable Pavers: 1 ac/ft of subsurface storage
    - Assume subsurface storage porosity is 0.3
- Additional storage can be provided in bioswales, amended soils, or cisterns.
- Increase Time of Concentration


Affects of LID Retrofits on Stormwater Runoff
Volume 2-yr 24-hr Event
Volume of Runoff in Acre-ft
20
15
10
5
0
Existing Conditions
Post LID Retrofit
Volume Reduced By Green Roofs
Volume Reduced By Permeable Pavement
Volume Reduced By Bioretention Cell
Site Runoff



- Vegetated Roofs
- Permeable Pavement
- Bioretension Cell
-Afforestation

Case Study Three: Big Box Site Development

A008114

V. REFERENCES

Big Box Retail Discussion. Columbia University, Graduate School of Architecture, Preservation, and Planning. Accessed November 28, 2005. http://www.columbia.edu/itc/architecture/bass/newrochelle/extra/big_box.html

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Minton, G. (2002). *Stormwater Treatment*, Resource Planning Associates. Seattle, WA.

Novotny, V. (2003). *Water Quality- Diffuse Pollution and Watershed Management*, John Wiley and Sons, Inc. New York, New York.

Urbonas, B.R. and P. Stahre (1993) *Stormwater: Best Management Practices and Detention for Water Quality, Drainage and CSO Management*, PTR Prentice Hall, Inc., Englewood Cliffs, NJ.

VI. APPENDIX A – Brief description of 14 additional LID BMPs

1	**BMP:**	Disconnect Impervious Areas/Downspout Disconnection
	Use:	Prerequisite
	Description:	Disconnection decouples roof leaders, roadways and other impervious areas from stormwater conveyance systems, allowing runoff to be collected and managed on site or dispersed into the landscape. Runoff is redirected onto pervious surfaces such as vegetated areas, reducing the amount of directly connected impervious area and potentially reducing the runoff volume and filtering out pollutants.
	Useful Links:	Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution. http://www.nrdc.org/water/pollution/storm/stoinx.asp Milwaukee Metropolitan Sewerage District http://www.mmsd.com/projects/downspout.cfm DC Greenworks http://www.dcgreenworks.org/LID/downspout.html
2	**BMP:**	Fingerprinting/ Impervious Areas Reduction
	Use:	Prerequisite
	Description:	Site fingerprinting, also known as minimal disturbance techniques, is a practice that minimizes ground disturbance by identifying the smallest possible land area that can practically be impacted during site development.
	Useful Links:	Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution. http://www.nrdc.org/water/pollution/storm/stoinx.asp Center for Watershed Protection. 1998. Better Site Design: A Handbook for Changing Development Rules in Your Community. Purdue University – Long-term impacts of Land Use Change http://www.ecn.purdue.edu/runoff/documentation/impacts/minimize.htm Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters EPA 840-B-92-002 January 1993 http://www.epa.gov/owow/nps/MMGI/Chapter4/ch4-2c.html
3	**BMP:**	Pollution Prevention
	Use:	Prerequisite
	Description:	Pollution Prevention (P2) is a general term for any activity or management action that reduces or eliminates pollutants before they are propagated downstream. The goal of P2 is to incorporate programs and techniques to keep nonpoint source (NPS) pollutants out of runoff.
	Useful Links:	Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution. http://www.nrdc.org/water/pollution/storm/stoinx.asp Water Related Best Management Practices (BMP's) in the Landscape, Center for Sustainable Design, Mississippi State University http://www.abe.msstate.edu/Tools/csd/NRCS-BMPs/pdf/water/source/prot_sd_hazwaste.pdf United States Environmental Protection Agency Office of Water. 1999. "Combined Sewer Overflow Management Fact Sheet: Pollution Prevention." Available at http://www.epa.gov/owm/mtb/pollutna.pdf EPA Pollution Prevention Program http://www.epa.gov/p2/
4	**BMP:**	Reforestation/ Afforestation
	Use:	Prerequisite
	Description:	Reforestation is the planting of trees in an area that was forested in the recent past (e.g. an area that was cleared for residential development). Afforestation is planting trees in an area where they were absent for a significant period of time (e.g. an old farm field or a riparian buffer). Plantings may be seeds, seedlings, or semi-mature trees.

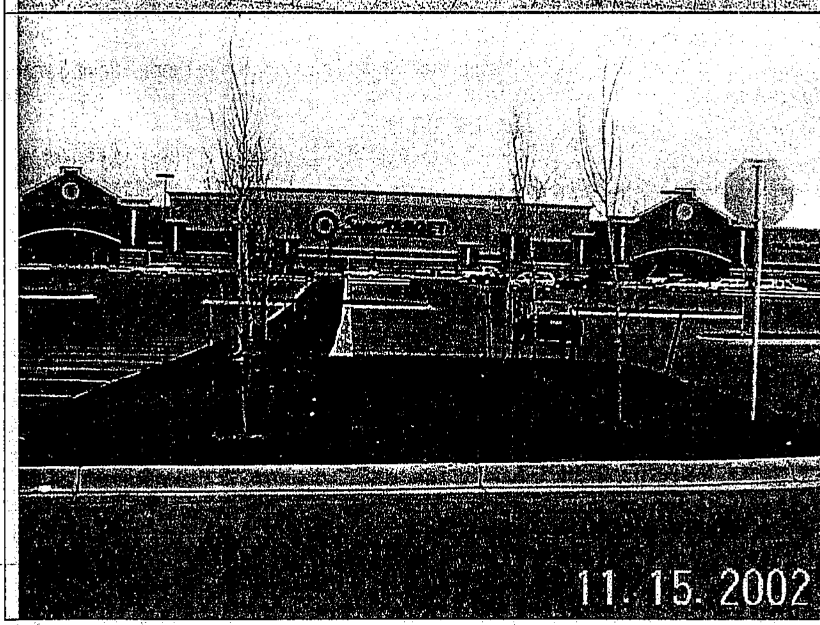
	Useful Links:	Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution. http://www.nrdc.org/water/pollution/storm/stoinx.asp Kentucky Division of Forestry – Reforestation Program http://www.forestry.ky.gov/programs/reforestation/ Reforestation Publications – NC State University College of Natural Resources http://www.ces.ncsu.edu/nreos/forest/reforestationpubs.htm
5	**BMP:**	Time of Concentration Practices/ Surface Roughening
	Use:	Secondary / Adjunct
	Description:	Time of concentration (t_c) practices, such as surface roughening, increase the time it takes for runoff to flow across a site to the drainage point or a BMP. Slowing runoff velocity potentially reduces erosion and increases the potential for infiltration. Increasing t_c is also directly related to the disconnection of impervious areas.
	Useful Links:	EPA Mid-Atlantic - National Environmental Policy Act (NEPA), LID http://www.epa.gov/reg3esd1/nepa/LID.htm New Low Impact Design: Site Planning and Design Techniques for Stormwater Management http://www.asu.edu/caed/proceedings98/Coffmn/coffmn.html
6	**BMP:**	Soil Amendments
	Use:	Secondary / Adjunct
	Description:	Soil amendments, which include both soil conditioners and fertilizers, make the soil more suitable for the growth of plants and increase water retention capabilities. Compost amendments and soils for water quality enhancement are also used to enhance native or disturbed and compacted soils. These measures change the physical, chemical, and biological characteristics of the soil allowing it to more effectively reduce runoff volume and filter pollutants. Soil amendments are valuable in areas with poor soils because they can help add available plant nutrients and sustain vegetative cover, reduce long-term erosion, and help reduce runoff peak volumes and discharges by absorption of rainfall and runoff.
	Useful Links:	Choosing a soil amendment, Colorado State University Cooperative Extension http://www.ext.colostate.edu/pubs/Garden/07235.html EarthWorks Soil Amendments, Inc. http://www.ewsa.com/ LID Center Soil Amendment Specification http://www.lowimpactdevelopment.org/epa03/soilamend.htm
7	**BMP:**	Environmentally Sensitive Landscaping
	Use:	Secondary / Adjunct
	Description:	Revegetating or landscaping a site using trees, shrubs, grasses, or other groundcover provides an opportunity to reintroduce native vegetation, which may be more disease-resistant and require less maintenance than non-native species. Long-term revegetation should only occur at sites at which future disturbance is not expected to occur.
	Useful Links:	Natural Resources Conservation Service. "Critical area planting." Urban BMP's - Water Runoff Management. ftp://ftp-fc.sc.egov.usda.gov/WSI/UrbanBMPs/water/erosion/critareaplant.pdf Natural Resources Conservation Service. "Native revegetation - grasses, legumes, and forbs." Urban BMP's - Water Runoff Management. ftp://ftp-fc.sc.egov.usda.gov/WSI/UrbanBMPs/water/erosion/natrevege_grasses.pdf Natural Resources Conservation Service. "Native revegetation - trees and shrubs." Urban BMP's - Water Runoff Management. ftp://ftp-fc.sc.egov.usda.gov/WSI/UrbanBMPs/water/erosion/natrevege_trees.pdf
8	**BMP:**	Flow Splitters
	Use:	Secondary / Adjunct

	Description:	A flow splitter allows the runoff volume from a drainage area to be split into two or more quantities ("sub-volumes"). Typically, flow splitters are used to isolate the water quality volume (WQV) in order to provide water quality treatment or manage a portion of a storm event with one or more BMPs. The WQV is typically defined as the first 0.5" to 1' of rain over the impervious drainage area. Alternately, a flow splitter can be used to divert high flows to prevent resuspension of captured pollutants in a BMP.
	Useful Links:	Split-flow Method http://www.forester.net/sw_0207_split.html Developing Split-flow Stormwater Systems http://www.epa.gov/owow/nps/natlstormwater03/11Echols.pdf Echols, S.P. 2002. Split-flow method: Introduction of a new stormwater strategy. Stormwater -The Journal for Surface Water Quality Professionals, 3(5): 16-32.
9	**BMP:**	Street Sweeping
	Use:	Secondary / Adjunct
	Description:	Street sweeping uses mechanical pavement cleaning practices to minimize pollutant transport to receiving water bodies. Sediment, debris, and gross particulate matter are the targeted pollutants, but removal of other pollutants can be accomplished as well. Street sweeping may also prevent pipes and outlet structures in stormwater detention facilities from becoming clogged with debris and trash. Different designs are available with typical sweepers categorized as (1) mechanical broom sweepers; (2) vacuum-assisted wet sweepers; and (3) dry vacuum sweepers. The effectiveness of street sweeping is very dependent upon when it is done and the number of dry days between storm events.
	Useful Links:	US EPA Office of Water http://www.epa.gov/owm/mtb/pollutna.pdf Low Impact Development Technologies http://www.wbdg.org/design/lidtech.php Protecting Water Quality from Urban Runoff, EPA 841-F-03-003 http://www.epa.gov/water/yearofcleanwater/docs/NPS_Urban-facts_final.pdf
10	**BMP:**	Dry Wells
	Use:	Limited / Occasional
	Description:	A dry well typically consists of a pit filled with large aggregate such as gravel or stone. Alternately, it may consist of a perforated drum placed in a pit and surrounded with stone. Dry wells capture and infiltrate water from roof downspouts or paved areas. The surface is typically at or just below existing grade. It may be covered by grass or other surface.
	Useful Links:	Massachusetts Low Impact Development Toolkit http://www.mapc.org/regional_planning/LID/Infiltration_trenches.html New Jersey Stormwater Best Management Practices http://www.state.nj.us/dep/watershedmgt/DOCS/BMP_DOCS/bmp2003pdfs/dec2003chap9_3.pdf Arizona Department of Environmental Quality http://www.ci.gilbert.az.us/environment/drywells.cfm
11	**BMP:**	Filtration Devices (Proprietary and Non-Proprietary)
	Use:	Limited / Occasional
	Description:	Filtration devices are installed in stormwater catch basins to remove mobilized pollutants before stormwater enters the collection system. These systems contain some type of filter media within a variety of configurations. Common filtration media includes fiberglass, activated carbon, and absorbent material. Geotextile materials may also be used both inside the basin or as curb inlet filters. Settling, filtration, absorption, and adsorption are the most common removal mechanisms. These devices are primarily intended to remove debris, trash, particulates, and oil and grease, but may also capture sediments.

	Useful Links:	Government of British Columbia, Ministry of Water, Land, and Air Protection: Water, Air, and Climate Branch http://wlapwww.gov.bc.ca/wat/wq/nps/BMP_Compendium/Municipal/Urban_Runoff/Treatment/Filter.htm Bioretention and LID, University of Maryland http://www.ence.umd.edu/~apdavis/Bio-research.htm
12	**BMP:**	Gutter Filters
	Use:	Limited / Occasional
	Description:	Gutter filters are linear pre-cast concrete gutter vaults containing gravel and finer (typically sand) filter media and an underdrain installed below grade at the curb line. They are especially useful for treating the "first flush" of roadway runoff, which contains elevated concentrations of many non-point source pollutants. A void space above the filter material captures trash and other debris that is able to pass through the surface grate while the gravel and sand filter media remove suspend solids and other pollutants. Filtered stormwater is conveyed by the underdrain from the gutter filter to the stormwater collection system. Gutter filters may be a stand-alone BMP or used in concert with other measures as part of a stormwater control strategy.
	Useful Links:	Virginia Department of Conservation and Recreation. 1999. "General intermittent sand filters." Virginia Stormwater Management Handbook, 3-12. http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-12.pdf

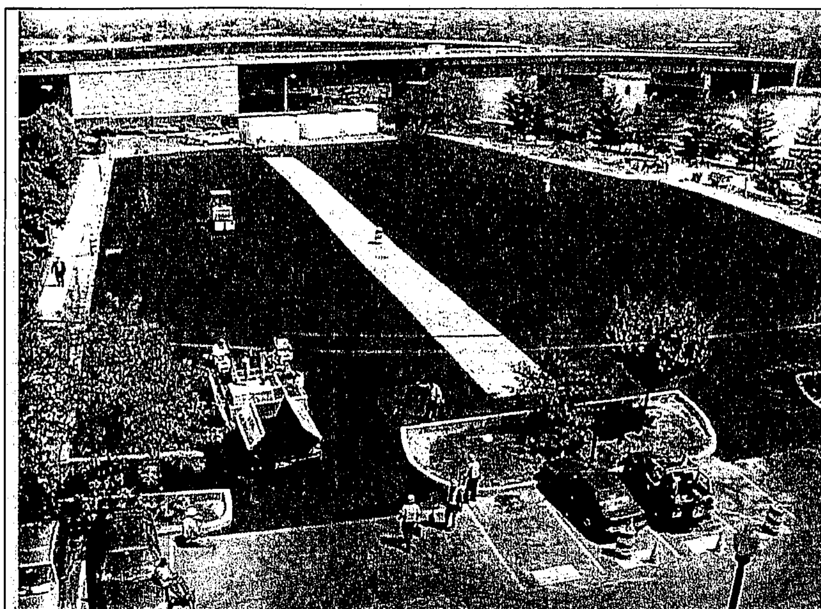
13	**BMP:**	Surface Sand Filters
	Use:	Limited / Occasional
	Description:	A sand filter is a flow-through system designed to improve water quality from impervious drainage areas by slowly filtering runoff through sand. It consists of one or more sedimentation and filtration chambers or areas to treat runoff. Pollutant removal in sand filters occurs primarily through straining and sedimentation. Treated effluent is collected by underdrain piping and discharged to the existing stormwater collection system. A sand filter occupies a small footprint compared to its drainage area. Surface and underground sand filters function similarly.
	Useful Links:	U.S. Environmental Protection Agency. 1999. Storm Water Technology Fact Sheet: Sand Filters. http://www.epa.gov/owm/mtb/sandfltr.pdf Naval Facilities Engineering Service Center. 2004. "Sand filter for treating storm water runoff." Joint Service Pollution Prevention Opportunity Handbook. http://p2library.nfesc.navy.mil/P2_Opportunity_Handbook/10-1.html Barrett, M.E. 2003. Performance, cost and maintenance requirements of Austin sand filters. Journal of Water Resources Planning and Management. May/June 2003: 234-242.
14	**BMP:**	Infiltration Strips (Percolation)
	Use:	Limited / Occasional
	Description:	Infiltration strips (also known as infiltration trenches, basins or galleries) are trenches that have been back-filled with stone. They collect runoff during a storm event and release it into the soil by infiltration.
	Useful Links:	US Environmental Protection Agency Office of Water. 1999. "Storm Water Technology Fact Sheet: Infiltration Trench." http://www.epa.gov/owm/mtb/infltrenc.pdf Stormwater Manager's Resource Center, Stormwater Management Fact Sheet: Infiltration Trench http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Infiltration%20Practice/Infiltration%20Trench.htm

VII. APPENDIX B – Image Gallery

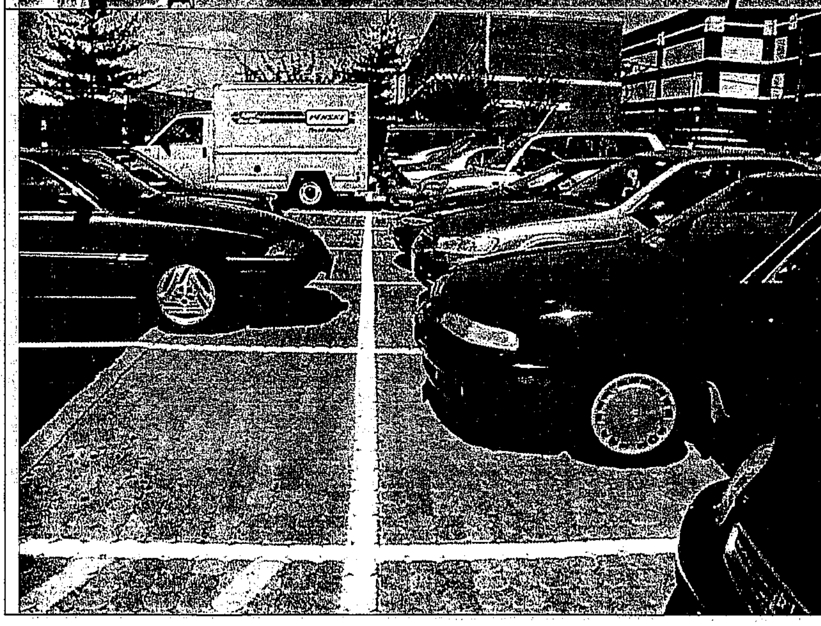
	IKEA Parking Lot ♦ Permeable Pavement ♦ Bioretention
	Super Target, Minnesota

Safeway Parking Lot
- Bioretention

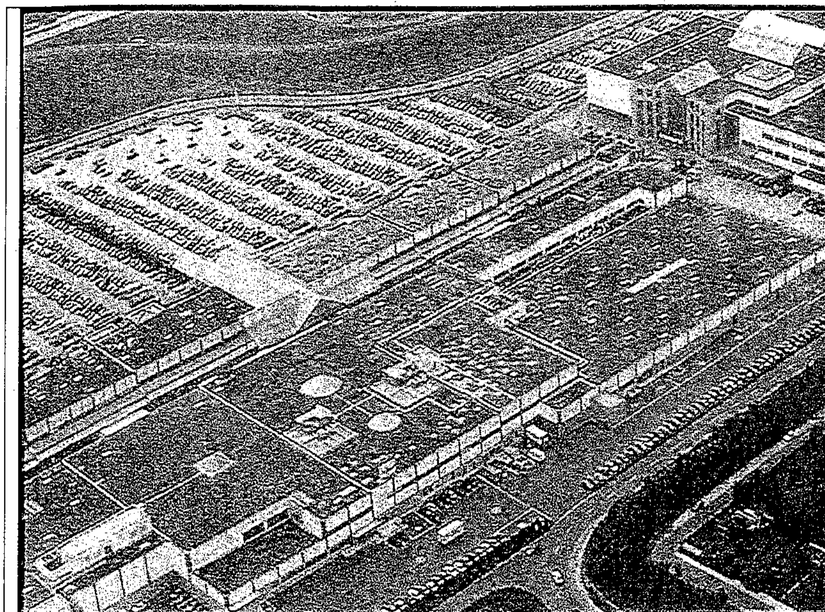
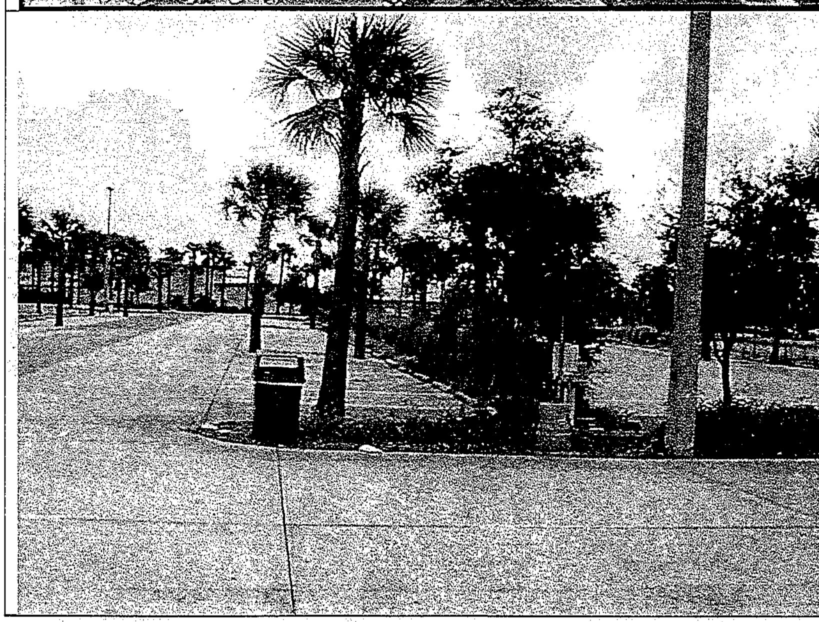
Permeable Pavement

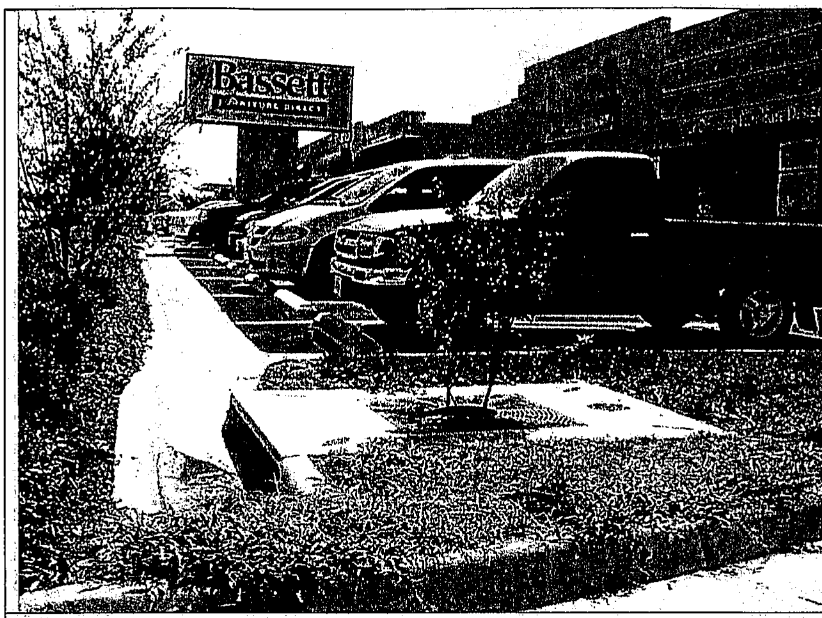


Washington Navy Yard Bldg 166 Under Construction
- Permeable Pavement



Washington Navy Yard Bldg 166 Completed
- Permeable Pavement

	◆ Green Roof
	◆ Bioretention Strip



- Tree Box Filter

- Bioretention Strip

VIII. APPENDIX C – Ten LID BMP Fact Sheets

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Fact sheets continue on next page.

VIII.1.Bioretention Basins

Bioretention incorporated into shopping center retrofit.
Source: LID Center

Advantages:

- Useful for larger drainage areas than rain gardens
- Useful incorporated within impervious areas (e.g. parking lots, traffic medians)
- Effective for retrofit
- Enhance quality of downstream waters
- Improve landscape appearance, absorb noise, provide and wind breaks
- Maintenance needs similar to any other landscaped area

Disadvantages:

- Not appropriate where the water table is within 6 feet (1.8m) of ground level
- Not recommended for areas with steep slopes (> 20%)
- Not recommended for areas where mature tree removal would be required
- Not recommended for areas with high sediment loads
- Not appropriate where surrounding soil is unstable

Design Criteria:

- Excavate to a minimum depth of one to three feet (deeper excavation can provide for additional storage in the soil or gravel layers, or more surface ponding)
- Cells ("rain gardens") contain grasses, perennials, shrubs, small trees and mulch
- A gravel layer provides temporary storage of stormwater, which will exit through an underdrain (if present) and/or through exfiltration into the subsoil.
- Underdrains and observation wells are recommended in areas with low subsoil permeability.
- Install surface or subsurface structure and high flow bypass to control discharge rate

Maintenance:

- Conduct routine periodic maintenance as required of any landscaped area.
- Inspect the treatment area's components and repair or replace them if necessary.
- Remove accumulated sediment and debris, replace any dead or distressed plants, and replenish mulch annually.
- Repair any eroded areas as soon as they are detected.
- The control structure should be inspected regularly for clogging and structural soundness.

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

Bioretention basins can be used to control 2-year, 2-hour and 10-year, 2-hour storms. Drainage areas handled by bioretention basins should be small and distributed.

Stormwater can be stored through surface ponding and through storage in soil and gravel layers. Voids in these layers provide stormwater storage capacity. Depths of the layers are sized to meet storage requirements.

Exfiltration into the subsoil can potentially reduce the volume of stormwater that ultimately enters the primary stormwater conveyance system.

Volume reduction depends upon:

- available storage in the gravel layer and ponding area
- the maximum flow rate into the subsoil
- and the flow rate into the basin related to
- storm intensity

Water Quality Controls

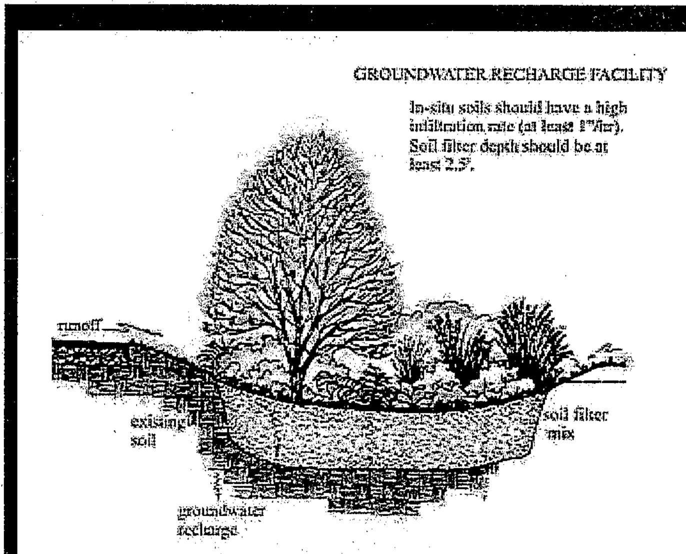
Typical phosphorus removal efficiencies for bioretention cells as follows:

- 50% removal for basins that capture 0.5" of runoff from impervious area
- 65% removal for basins that capture 1.0" of runoff from impervious area

Location

Bioretention cells can be used in commercial and industrial areas. Potential applications include median strips and parking lots.

Bioretention cells should not be located in areas of high sediment loads or where the site is not entirely stabilized.



Bioretention Cell Schematic
Source: DER - Prince Georges County, MD

Cost

The cost for a bioretention basin to treat runoff from ½ impervious acre consists of both the installation and annualized costs.

These cost calculations were based upon a bioretention basin with a surface area of 900 square feet, sized to treat the first 0.5" of runoff. A contingency of 50 percent was added to installation and replacement costs to account for additional excavation and materials needed to provide storage for larger storm events.

A bioretention basin is assumed to have a lifespan of 25 years, at which point it will be removed and replaced.

Design Construction and Materials

Bioretention basins are excavated to a depth of one (1) to three (3) feet, depending on the infiltration rate and depth to the seasonal high groundwater table or bedrock. Deeper excavation can provide more storage in soil and gravel layers or more surface ponding.

Underdrains are recommended in areas with low subsoil permeability (e.g. compacted or clay soils) or shallow soil profiles. Underdrains must tie into an adequate conveyance system. Observation wells should be installed if underdrains are used.

A gravel layer provides temporary storage of stormwater, which will exit through an underdrain (if present) and/or through exfiltration into the subsoil. If an underdrain is present, the gravel layer surrounds the underdrain pipe to minimize the chance of clogging.

The excavated area is filled with an engineered media classified as "sandy loam" or "loamy sand" that typically consists of:

- o 50% sand
- o 30% planting soil with minimal clay content, and
- o 20% shredded hardwood mulch.

Depending on space constraints and drainage area characteristics, a pretreatment device (e.g. vegetated filter strip) can be created to intercept debris and large particles.

Item	Unit	Estimated unit cost (2005 Dollars)
Excavation	C.Y.	$8 - $10
Bioretention media	C.Y.	$40 - $60
Filter fabric	S.Y.	$1 - $5
Gravel	C.Y.	$30 - $35
Underdrain (perforated pipe 4" dia.)	L.F.	$8 - $15
Plants	Ea.	$5 - $20
Mulch	C.Y.	$30 - $35

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	…	25
Installation[1]	15,000												
Mulching and Debris Removal		350	350	350	350	350	350	350	350	350	350		
Replace Vegetation		200	200	200	200	200	200	200	200	200	200		
Remove & Replace													15,000
Total Cost	15,000	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**		**15,000**
Annualized Cost	$1,125 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

The primary maintenance requirement for bioretention cells is to inspect the treatment area's components and repair or replace them if necessary. Generally, maintenance is the same as the routine periodic maintenance that is required of any landscaped area

Removal of accumulated sediment and debris, replacement of any dead or stressed plants, and replenishment of the mulch layer is recommended on an annual basis. Also, any eroded areas should be repaired as soon as they are detected. The control structure should be inspected regularly for clogging and structural soundness.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)

Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/OW-OWM.html/mtb/biortn.pdf

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

United States Environmental Protection Agency, 2000: Bioretention applications: Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. Office of Water, Washington, D.C., EPA-841-B-00-005A

U.S. Environmental Protection Agency, 1995: Maryland developer grows 'Rain Gardens' to control residential runoff. Nonpoint Source News-Notes, 42 (August/September)
http://www.epa.gov/NewsNotes/issue42/urbrnf.html

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly into each bioretention cell. Water standing in a bioretention cell for more than 48 hours indicates operational problems.

Corrective measures include inspection for and removal of sediments, typically by backflushing.

Samples of bioretention media should be assessed if there is poor infiltration to determine the condition of the media (e.g. clay content).

Replacement of the bioretention media may be required to restore the flow rate through the cell. First, applying soil amendments can be attempted to restore permeability.

Perform inspection:

- annually in spring
- after severe weather events (e.g. hurricanes)

VIII.2. Bioretention Cells

Bioretention cell in a commercialr parking lot
Source: LID Center, Inc

Advantages:

- Useful for small drainage areas
- Useful in impervious areas (e.g. parking lots, traffic medians)
- Effective for retrofit
- Enhance the quality of downstream water bodies
- Improve landscape appearance, absorb noise, provide shade and wind breaks
- Maintenance needs similar to any other landscaped area

Disadvantages:

- Not recommended for areas where mature tree removal would be required
- Not recommended for areas with high sediment loads
- Not appropriate where the surrounding soil stratum is unstable
- Not applicable for large drainage areas

Design Criteria:

- Excavated to a minimum depth of one to three feet (deeper excavation can provide for additional storage in the soil or gravel layers, or more surface ponding)
- Cells, or "rain gardens," contain grasses and perennials, shrubs, and small trees
- A gravel layer provides temporary storage of stormwater, which will exit through an underdrain (if present) and/or through exfiltration into the subsoil.
- Underdrains are recommended in areas with low subsoil permeability. Observation (cleanout) wells should also be installed, if underdrains are used.

Maintenance:

- Conduct routine periodic maintenance as required of any landscaped area.
- Inspect the treatment area's components and repair or replace them if necessary.
- Remove accumulated sediment and debris, replace any dead or distressed plants, and replenish the mulch layer on an annual basis.
- Repair any eroded areas as soon as they are detected.

Stormwater Management Suitability

Runoff Volume Reduction

Water Quality

Water Quantity Controls

Stormwater in excess of the water quality volume (WQV: see section below) can be detained by allowing additional ponding and/or subsurface storage in the bioretention cell, thereby reducing the runoff volume and peak discharge rate. Voids in the soil and gravel layers provide stormwater storage capacity.

The depth of the gravel layer may be increased to add storage capacity. Exfiltration into the subsoil can reduce the volume of stormwater that ultimately enters the conveyance system. Volume reduction depends on the available detention storage in the gravel layer and ponding area. It also is a function of the flow rate into the cell and the maximum flow rate into the subsoil. These factors are related to the storm intensity and drainage area size.

Water Quality Controls

The water quality volume (WQV) is typically defined as the first one-half to one inch of runoff from impervious areas.

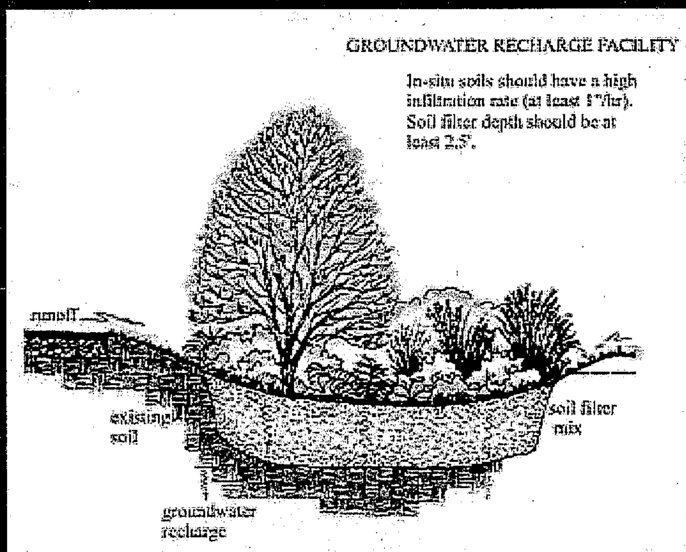
Typical phosphorus removal efficiencies for bioretention cells as follows:

- 50% removal for cells that capture 0.5" of runoff from an impervious area
- 65% removal for cells that capture 1.0" of runoff from an impervious area

Location

Bioretention cells can be used in commercial and industrial areas. Potential applications include median strips, parking lots, and swales.

Bioretention cells should not be located in areas of high sediment loads or where the site is not entirely stabilized.



Bioretention Cell Schematic
Source: DER - Prince Georges County, MD

Cost

Cost of a bioretention cell to treat runoff from ½ impervious acre consists of both installation costs and annualized costs.

Cost calculations were based upon a bioretention cell with a surface area of 900 square feet, sized to treat the first 0.5" of runoff.

A bioretention cell is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Bioretention cells are excavated to a depth of one (1) to three (3) feet, depending on the infiltration rate and depth to the seasonal high groundwater table or bedrock. Deeper excavation can provide for more storage in soil or gravel layers.

Underdrains are recommended in areas with low subsoil permeability (e.g. compacted or clay soils) or shallow soil profiles. Underdrains must tie into an adequate conveyance system. Observation wells should be installed if underdrains are used.

A gravel layer provides temporary storage of runoff which may exit through an underdrain and/or through exfiltration into the subsoil. If an underdrain is present, the gravel layer surrounds the underdrain pipe to minimize the chance of clogging.
The excavated area is then filled with an engineered media classified as "sandy loam" or "loamy sand" that typically consists of:

- 50% sand
- 30% planting soil with minimal clay content, and
- 20% shredded hardwood mulch.

The area is then mulched and planted with shrubs, perennials, grasses, and small trees. The cell must provide for bypass flow into an inlet or overflow weir.

Bioretention cells typically consist of the cost components below.

Item	Unit	Estimated unit cost (2005 Dollars)
Excavation	C.Y.	$8 - $10
Bioretention media	C.Y.	$40 - $60
Filter fabric	S.Y.	$1 - $5
Gravel	C.Y.	$30 - $35
Underdrain (perforated pipe 4" dia.)	L.F.	$8 - $15
Plants	Ea.	$5 - $20
Mulch	C.Y.	$30 - $35

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	...	25
Installation[1]	10,000												
Mulching and Debris Removal		350	350	350	350	350	350	350	350	350	350		
Replace Vegetation		200	200	200	200	200	200	200	200	200	200		
Remove & Replace													10,000
Total Cost	10,000	550	550	550	550	550	550	550	550	550	550		10,000
Annualized Cost	$925 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

The primary maintenance requirement for bioretention cells is to inspect the treatment area's components and repair or replace them if necessary. Generally, maintenance is the same as the routine periodic maintenance that is required of any landscaped area

Removal of accumulated sediment and debris, replacement of any dead or stressed plants, and replenishment of the mulch layer is recommended on an annual basis. Also, any eroded areas should be repaired as soon as they are detected.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)

Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)

Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)

Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/OW-OWM.html/mtb/biortn.pdf

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

United States Environmental Protection Agency, 2000: Bioretention applications: Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. Office of Water, Washington, D.C., EPA-841-B-00-005A

U.S. Environmental Protection Agency, 1995: Maryland developer grows 'Rain Gardens' to control residential runoff. Nonpoint Source News-Notes, 42 (August/September)
http://www.epa.gov/NewsNotes/issue42/urbrnf.html

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly into each bioretention cell. Water standing in a bioretention cell for more than 48 hours indicates operational problems.

Corrective measures include inspection for and removal of sediments, typically by backflushing.

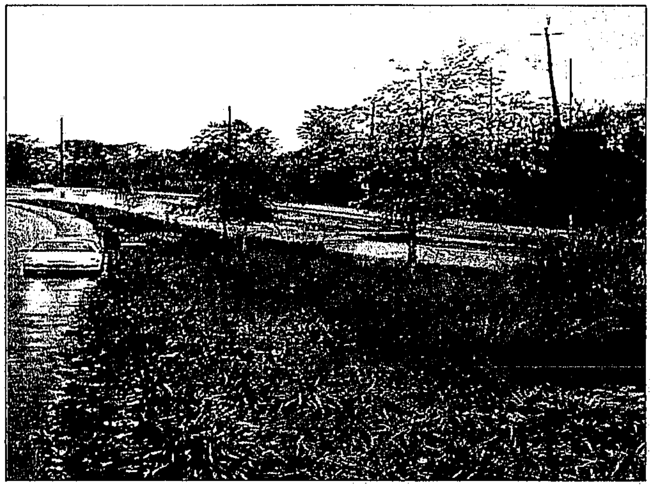
Samples of bioretention media should be assessed if there is poor infiltration to determine the condition of the media (e.g. clay content).

Replacement of the bioretention media may be required to restore the flow rate through the cell. First, applying soil amendments can be attempted to restore permeability.

Perform Inspection:

- annually in spring
- after severe weather events (e.g. hurricanes)

VIII.3.Bioretention Slopes



Highway median: potential bioslope location
Source: LID Center

Design Criteria:

- Construct a bioslope along the entire length of the sloped edge of its drainage area, having a width sufficient to provide treatment for the drainage area runoff
- Cover slope with an ecology mix soil having a minimum depth of one foot
- Install a gravel level spreader between the impervious surface and the slope
- Install a vegetated filter strip between the gravel and the bioslope, if pre-treatment is desired or needed
- Install a gravel underdrain trench and pipe at the base of the slope for temporary storage of stormwater.
- Plant (seed) the slope with grasses

Maintenance:

- Periodically remove debris accumulated on the gravel level spreader.
- Mow the grass filter strip with a retractable –arm mower to avoid compaction of the ecology mix.
- Reseed bare areas annually.
- Repair any eroded areas as soon as they are detected.
- Conduct periodic sampling and testing to assess adequate ongoing permeability of the ecology mix.

Advantages:

- **Useful for medians and side slopes of access roads/sites**
- **Useful along edges of elevated impervious areas (e.g. parking lots)**
- **Effective for retrofit of standard fill slopes**
- **Enhance quality of downstream waters**
- **Reduce runoff volume and pollutant loads**

Disadvantages:

- **Not recommended for unstable slopes or those steeper than 4:1 (rise : run)**
- **Runoff must flow onto the bioslope via sheet flow only**
- **Bioslopes cannot handle high velocity and high discharge flows.**
- **Bioslopes are susceptible to erosion**
- **Requires specialized mowing equipment (retractable arm) to avoid compaction**

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

Bioslope design is based on the ability of a slope area to absorb and treat a specified storm intensity. This assumed design rainfall intensity typically relates to the maximum anticipated intensity of the water quality storm event.

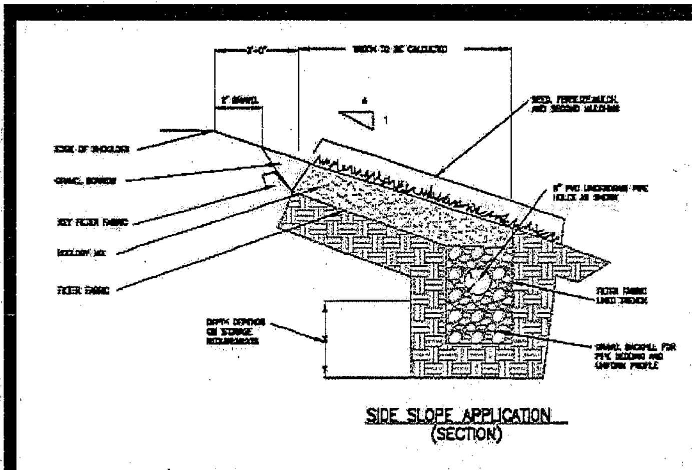
For storms with an intensity greater than the design rainfall intensity, some runoff will not be captured and infiltrated, but will flow over the surface of the bioslope. Stormwater not captured by the bioslope can be detained through additional (sub)surface storage at the base of the bioslope.

A ponding area or gravel storage bed (infiltration trench) can be constructed at the slope base to store excess runoff. It is important to emphasize that storm intensity, not rainfall depth, will determine the volume of "excess" stormwater that will need to be stored at the base of the bioslope. For the bioslope itself and the auxiliary storage area, the permeability of the subsoil will determine whether captured runoff will exfiltrate into the subsoil or flow into an underdrain connected to a conventional conveyance system.

Additional subsurface storage can be provided within the bioslope itself by enlarging the gravel underdrain trench. This can be used to store water that would otherwise flow directly into the underdrain pipe.

Water Quality Controls

Research conducted by the Washington State Department of Transportation has found that bioslopes can remove 60 percent of phosphorus, 77 percent of metals, and 88 percent of total suspended solids (TSS) contained in stormwater runoff from a water quality storm event.



Bioslope Cross-Section
Source: Washington State Highway Runoff Manual

Location

Bioslopes are appropriate for use on medians and side slopes of access roads or sites but cannot be used where the side slope exceeds 4:1 (rise : run) or on unstable slopes.

To avoid erosion, stormwater must run onto the bioslope via sheet flow only. High velocity and high discharge flows must be diverted to conveyance channels.

Cost

The cost for a bioslope to treat runoff from ½ impervious acre is consists of both the installation and annualized costs.

These cost calculations were based upon a bioslope with a surface area of 3,000 square feet.

A bioslope is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Bioslopes consist of a gravel level spreader next to the pavement to evenly distribute flows and trap sediments; an optional vegetated filter strip to provide additional pretreatment if space allows; an ecology mix bed which provides the majority of water quality improvement; and an optional gravel underdrain trench and pipe.

Underdrains may be needed on Hydrologic Soil Group (HSG) C and D soils. Observation/cleanout wells should be installed, if underdrains are used. Soil amendments may be used in the filter strip to increase its permeability.

When sizing a bioslope for its drainage area, the long-term flow rate through the ecology mix must be at least as great as the design peak discharge rate from the drainage area. Include a 50 percent safety factor when assigning a long-term conductivity rate to the ecology mix.
Basic bioslope dimensions are given below.

- The bioslope should be as long as the drainage area it is intended to treat and should run parallel along the sloped edge of the drainage area (e.g. roadway).
- The bioslope width must be sufficient to provide treatment for the adjacent drainage area.
- Dual bioslopes must be at least two feet (2') wide.
- The ecology mix soil bed should be one foot (1') deep or greater.
- The side slope of the bioslope should be no steeper than 4H:1V.
  - The gravel level spreader should be at least one foot (1') wide and at least 18 inches deep.
  - The gravel underdrain trench should be at least two feet (2') wide.

Item	Unit	Estimated unit cost (2005 Dollars)
Level spreader (gravel)	C.Y.	$30 - $35
Filter fabric	S.Y.	$1 - $5
Underdrain trench (gravel)	C.Y.	$30 - $35
Underdrain (perforated pipe 8" dia.)	L.F.	$8 - $15
Grass seed or sod	M.S.F.	$15 - $20
Ecology mix	C.Y.	$40 - $60

The ecology mix consists of the following components (per WSDOT standards).

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	...	25
Installation[1]	10,000												
Mowing		150	150	150	150	150	150	150	150	150	150		
Reseeding		50	50	50	50	50	50	50	50	50	50		
Remove & Replace													10,000
Total Cost	10,000	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**		**10,000**
Annualized Cost	$600 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

Periodically remove any debris that has accumulated on the gravel level spreader and mow the grass filter strip. Use a retractable-arm mower to avoid compaction of the ecology mix. Both activities can be incorporated into regular maintenance activities.

Reseed bare areas annually. Conductivity tests may be used periodically to determine whether the permeability of the ecology mix decreases over time.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)

Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/OW-OWM.html/mtb/biortn.pdf

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

United States Environmental Protection Agency, 2000: Bioretention applications: Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. Office of Water, Washington, D.C., EPA-841-B-00-005A

U.S. Environmental Protection Agency, 1995: Maryland developer grows 'Rain Gardens' to control residential runoff. Nonpoint Source News-Notes, 42 (August/September)
http://www.epa.gov/NewsNotes/issue42/urbrnf.html

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly into the bioslope. Problems are indicated by channelized flow down the slope or rill formation.

Corrective measures include inspection for accumulated sediments around the level spreader and their removal, if necessary.

If infiltration is poor, samples of the ecology mix should be assessed to determine the condition of the ecology mix. The mix may need to be replaced if it has deteriorated.

Perform inspection:

- annually in spring
- after severe weather events (e.g. hurricanes)

VIII.4.Bioretention Swales

Bioretention Swale
Source: Portland BES

Design Criteria:

- Depth shall be one (1) to three (3) feet, minimum (greater depth can provide more storage in soil or gravel layers or more surface ponding)
- Contains mulch, grasses and herbaceous annuals and perennials (typically natives)and special bioretention media
- A gravel layer provides temporary storage of stormwater, which will exit through an underdrain (if present) and/or through exfiltration into the subsoil.
- Underdrains are recommended in areas with low subsoil permeability. Observation (cleanout) wells should also be installed.
- Use inlets or overflow weirs for bypass flow, check dams for encouraging sheet flow

Maintenance:

- Conduct routine periodic maintenance including mowing (to design flow depth), verifying hydraulic efficiency of the channel, insuring dense, healthy cover
- Inspect the treatment area's components and repair or replace them if necessary.
- Remove accumulated sediment and debris, replace any dead or distressed plants, and replenish mulch annually.
- Repair any eroded areas as soon as they are detected. Reseed bare areas.

Advantages:

- **Useful incorporated with linear impervious areas (e.g. roads)**
- **Improve on standard grassed swales by affording greater infiltration, water retention, nutrient/ pollutant removal**
- **Effective for retrofit**
- **Enhance quality of downstream waters, as well as reducing runoff volume and peak runoff rate**
- **Improve roadway corridor appearance**

Disadvantages:

- **Not recommended for areas where the slope in the direction of flow exceeds 5 percent due to risk of erosive velocities**
- **Not appropriate where the water table is within 6 feet (1.8m) of ground level**
- **Not appropriate where surrounding soil is unstable**
- **Not recommended for areas with high sediment loads**

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

Any volume of stormwater in excess of the water quality volume (WQV) can be detained by providing additional ponding and/or subsurface storage in the bioswale, thereby reducing the runoff volume and peak discharge rate.

The voids in the soil and gravel layers provide storage capacity. Additional storage may be provided by increasing the depth of the gravel layer. Exfiltration into the subsoil can potentially reduce the volume of stormwater that ultimately enters the conveyance system.

Volume reduction depends upon:

- available storage in the gravel layer and ponding area
- the maximum flow rate into the subsoil
- the flow rate into the basin related to
- storm intensity
- drainage area size

A bioswale's cross-section can be sized to provide conveyance for any given design storm, as required by applicable regulations.

Water Quality Controls

Phosphorus removal efficiency data specific to bioswales is not available. Similarities in design and function of swales to bioretention cells (see Section 2.2) allow phosphorus removal efficiencies for bioretention cells to be used as a reference for bioswales.

Therefore, bioswale phosphorus removal efficiencies are:

- 50 percent for swales that capture 0.5" runoff from the impervious area
- 65 percent for swales that capture 1.0" runoff from impervious the area

Bioswale Maintenance
Source: LID Center

Location

Bioswales can be used in commercial and industrial areas. Use of pre-treatment BMPs in conjunction with bioswales may be advisable. Sediment capturing devices such as filter strips and vegetated filters are examples of these optional techniques.
Bioswales generally should not be located where there are high sediment loads or soils are not entirely stabilized.

Cost

The cost for a bioswale to treat runoff from ½ impervious acre consists of both the installation and annualized costs.

Cost calculations were based upon a bioswale design having a surface area of 900 square feet.

A bioswale is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Bioswales are excavated to a minimum depth of one (1) to three (3) feet, depending on the infiltration rate and depth to the seasonal high groundwater table or bedrock. Deeper excavation can provide for additional storage in the soil or gravel layers.

Underdrains are recommended in areas with low subsoil permeability (e.g. compacted or clay soils) or shallow soil profiles. Underdrains must tie into an adequate conveyance system. Observation/ cleanout wells should also be installed if underdrains are used.

A gravel layer provides temporary storage of stormwater, which will exit through an underdrain (if present) and/or through exfiltration into the subsoil.
If an underdrain is present, the gravel layer surrounds the underdrain pipe to minimize clogging. The excavated area is then filled with an engineered media classified as "sandy loam" or "loamy sand" that consists of:

- 50% sand
- 30% planting soil with minimal clay content, and
- 20% shredded hardwood mulch.

The swale area is then seeded to provide a plant community of warm season grasses, herbaceous annuals and flowering perennials.

The swale must provide for bypass flow into an inlet or overflow weir. Check dams may be used to act as flow spreaders to encourage sheet flow.
Bioswale slopes should be no greater than 5 percent. Gentle slopes and reduced velocities are critical to ensuring a stable, non-erosive swale.

Item	Unit	Estimated unit cost (2005 Dollars)
Excavation	C.Y.	$8 - $10
Grading	S.Y.	$0.10 - $0.15
Bioretention media	C.Y.	$40 - $60
Filter fabric	S.F.	$0.70 - $1.00
Underdrain trench (gravel)	C.Y.	$30 - $35
Underdrain (perforated pipe 8" dia.)	L.F.	$15 - $20
Seed	S.F.	$1 - $2

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	...	25
Installation[1]	10,000												
Mowing		100	100	100	100	100	100	100	100	100	100		
Reseeding / Replanting		100	100	100	100	100	100	100	100	100	100		
Remove & Replace													10,000
Total Cost	**10,000**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**		**10,000**
Annualized Cost	$600 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

The primary maintenance requirement for bioswales includes routine inspections targeted at maintaining hydraulic efficiency of the channel, the treatment effectiveness of the bioretention components, and a dense, healthy vegetative cover. Inspections should also target erosion of the swale channel bottom.

Maintenance activities should include periodic mowing (with grass never cut shorter than the design flow depth), clearing of debris and blockages, and sediment removal. Reseed bare areas annually.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)

Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/OW-OWM.html/mtb/biortn.pdf

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

United States Environmental Protection Agency, 2000: Bioretention applications: Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. Office of Water, Washington, D.C., EPA-841-B-00-005A

U.S. Environmental Protection Agency, 1995: Maryland developer grows 'Rain Gardens' to control residential runoff. Nonpoint Source News-Notes, 42 (August/September)
http://www.epa.gov/NewsNotes/issue42/urbrnf.html

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly and is being conveyed through the length of the bioswale. Water standing in a bioswale for more than 48 hours indicates operational problems.

Corrective measures include inspection for and removal of sediments, typically by backflushing.

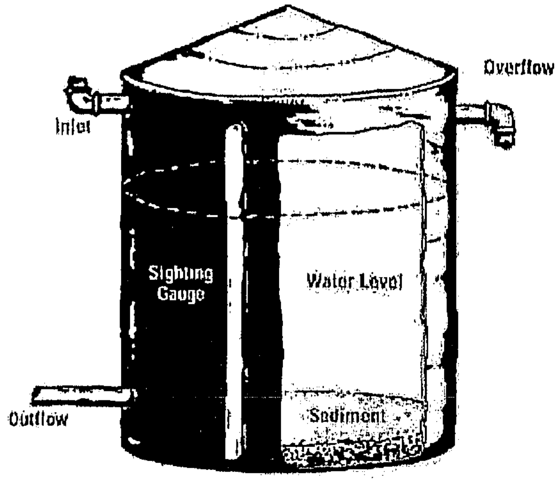
Samples of bioretention media should be assessed if there is poor infiltration to determine the condition of the media (e.g. clay content).

Replacement of the bioretention media may be required to restore the flow rate through the cell. First, applying soil amendments can be attempted to restore permeability.

Perform inspection:

- annually in spring
- after severe weather events (e.g. hurricanes)

VIII.5.Cisterns / Rainbarrels



Schematic of Cistern. Source: Texas Water Development Board- Rainwater Harvesting

Design Criteria:

- Rainwater catchment systems (RWCS) store roof runoff for reuse.
- Cisterns may store up to 10,000 gallons of stormwater runoff. Prefabricated systems offer greater reliability and ease of integration with plumbing systems. These can be placed on rooftops and drained by gravity. If installed in a basement, pumping is required. An overflow to the sanitary sewer should also be provided.
- Rain barrels typically store less than 100 gallons of runoff. Homemade rain barrels can be easily constructed from readily available materials.

Maintenance:

- Rain Barrels
  Inspect each unit and its components seasonally and after major rain events for clogging.
  Replace minor parts as needed.

- Cisterns
  Inspect for clogging and structural soundness - and test water quality - twice each year. Repair as needed.
  Remove accumulated sediment once annually.

Advantages:

- Allows capture and reuse of roof runoff – relatively clean, naturally "soft" water, free of most sediment and dissolved salts
- Reduces runoff volume, as well as peak discharge rate for small, frequent rain events
- Reduces potable water consumption:
  - landscape irrigation
  - HVAC coolant
  - toilet flushing
- Affords water quantity and quality control where space is scarce and land values are premium
- Effective for urban retrofit sites

Disadvantages:

- Unless provided in large quantities, rain barrels may not be able to handle the water quality volume (WQV)
- Regulatory and administrative obstacles may preclude the re-use of cistern water. This may reduce the attractiveness and feasibility of this BMP given space needs and costs.

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

For any storm, the runoff volume will be reduced by an amount equal to the empty volume of the RWCS, which may be less than the total storage capacity. The peak discharge rate may be delayed or reduced, depending on captured volume.

Rain barrel sizing is relatively simple. Rain barrels usually store between 55 and 130 gallons and may be connected in series. Space constraints and frequency and volume of irrigation will determine the number of rain barrels used for a rooftop.

Cistern sizing depends on the water demand and on the collection volume: in other words, an analysis of the water input and output. Storage in addition to the WQV (water quality volume) may be needed if cistern water is not completely drawn down between storms. Per capita use of cistern water (e.g. toilet flushes per person per day) can be used to calculate the demand, i.e. the cistern outflow rate.

Water Quality Controls

Typically, to be considered a water quality BMP, a RWCS must collect the water quality volume (WQV), which is the first 0.5" of rainfall (NVPDC). Unless provided in large quantities, rain barrels may be unable to meet this requirement.

For all RWCS, settling of sediments will contribute to water quality improvements (however, resuspension during subsequent storms may be a concern). Additional pollutant removal ability will depend on the ultimate use of the water.

Since rain barrel water is typically used for landscape irrigation, pollutant removal rates approximate those of infiltration BMPs (see 2.2, bioretention cells). The same holds true for cistern water used for landscape irrigation.

If cistern water is used for toilet flushing or other applications in which it will ultimately be discharged to the sanitary sewer, the pollutant removal rate is the same as that of the wastewater treatment plant (WWTP). This efficiency is 95 to 100 percent for phosphorus and many other pollutants.

Location

RWCS can be used on any building site with sufficient space and structural capacity where there will be a reliable end use for collected rainwater. Cisterns may be installed for any land use. Rain barrels are often, but not exclusively, used for residential applications due to their small capacity.

Cost

Cost calculations were developed assuming the first 0.5" of rainfall is captured.
Cost for a large cistern to treat runoff from ½ impervious acre consists of installation and annualized costs.

For similar capacity, a series of 53 rain barrels (130 gal/each) would be required. Their primary purpose would be to increase visibility of the system in order to raise public awareness of stormwater issues.

Both cisterns and rain barrels are assumed to have a lifespan of 25 years, at which point they would be removed and replaced.

Design Construction and Materials

Cisterns and rain barrels may be constructed from available parts, but prefabricated systems may offer more reliability and greater ease of integration with the building's plumbing system. If adequate structural capacity exists, cisterns can be placed on rooftops and be drained by gravity. Another common installation location is a basement, in which case pumping is needed. Flow splitters can be used to divert the WQV to the cistern. An overflow to the sanitary sewer should also be provided.

If cisterns are used to supplement a building's potable plumbing system, a parallel plumbing system will need to be installed. The installation cost depends on the size and purpose of the system and will need to be considered in any cost-benefit analysis. Safety measures must be taken to ensure that cistern water not be used for potable purposes. Besides a parallel plumbing system, such measures include warning signs and lockable faucets.

Cistern/Rain Barrel Type	Small system	Large system
Galvanized steel	\$225 → 200 gal.	\$950 → 2000 gal.
Polyethylene	\$150 → 130 gal.	\$1100 → 1800 gal.
Fiberglass	\$660 → 350 gal.	\$10,000 → 10K gal.
Fiberglass/steel composite	\$300 → 300 gal.	\$10,000 → 5K gal.
Ferro-cement	Varies by location	Varies by location

Item	Required Cost per Year – Cistern[2] (2005 Dollars)												
	0	1	2	3	4	5	6	7	8	9	10	...	25
Installation[1]	13,000												
Debris Removal		250	250	250	250	250	250	250	250	250	250		
Replace Parts				500			500			500			
Water Quality Tests		500	500	500	500	500	500	500	500	500			
Remove & Replace													13,000
Total Cost	**13,000**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**		**13,000**
Annualized Cost	\$1,400 / year (includes replacement in year 25)												

[1]Developer Cost (assumes 10,000 gallon fiberglass cistern). Not included in annualized cost.
[2]Comparable capacity using rain barrels results in installed cost of \$7,950 and annualized costs of \$720 including replacement.

Maintenance

Maintenance requirements for rain barrels are minimal. Each unit and its attachments should be inspected for clogging several times a year and after major storms. Minor parts such as spigots, screens, downspouts or leaders may need to be replaced periodically.

Cisterns should undergo water quality assessments (i.e. sediment, fecal coliform, bacteria, and heavy metals) and inspections for clogging and structural soundness twice each year. Accumulated sediment should be removed once annually. Costs associated with inspection and repair of the distribution system (parallel plumbing) are widely variable.

Potential LEED Credits

Primary: Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Water Efficiency – Credit 3 "Water Efficient Landscaping" (1-2 Points)
Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)

Other: Innovative & Design Process (1-4 Points)

Innovation & Design Process (1-4 Points)

Links to Additional Information

Downspout Disconnection in Toronto,
www.city.toronto.on.ca/watereff/downspot.htm

Rainwater harvesting from Rooftop catchments
www.oas.org/usde/publications/Unit/oea59e/ch10.htm

Tanks Direct, Above ground and underground storage for water, petroleum, and chemical applications
www.storagetanks.com

The Texas Water Development Board-Rainwater Harvesting
www.twdb.state.tx.us/assistance/conservation/Rain.htm

Performance and Inspection

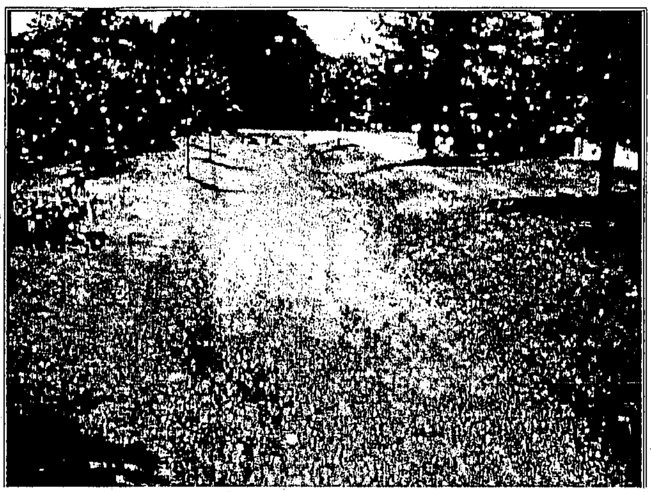
Inspect rain barrels once each season) and after extreme weather events, checking connections (e.g. inflow and outflow hoses) when removing debris.

Inspect cisterns twice each year for structural soundness; one of these times may coincide with annual sediment removal.

If there is a parallel plumbing system, it can be inspected at the same time as the conventional plumbing system.

Rain Barrel
Source: District of Columbia Water & Sewer Authority

VIII.6.Water Quality Swales



Grassed Swale
Source: LID Center

Advantages:

- Useful for small drainage areas with low stormwater velocities
- Use existing natural low areas to treat stormwater
- Can be sized to convey any design storm required
- Reduce stormwater volume
- Enhance quality of downstream waters
- Reduce runoff velocity
- Minimal maintenance requirements

Disadvantages:

- Not applicable to large drainage areas in excess of 10 acres (much smaller areas are recommended)
- Not recommended for areas with slopes greater than 5% or where velocities exceed 3 to 4 feet per second --- without the use of check dams
- Not applicable where soil infiltration rates are less than 0.3 inches per hour

Design Criteria:

- Broad, shallow channel vegetated along bottom and sides with grasses designed to accommodate peak flow of design storm
- Side slopes must be 3:1 (rise : run) or less
- Slope in flow direction must be 5 percent or less
- Grass along sides of channel is kept at a height greater than the maximum design stormwater volume
- Soils must have a minimum permeability rate of 0.27 inches per hour (SCS A/B soils groups) or be improved with amendments
- An optional gravel layer can provide storage of stormwater in excess of WQV; engineered soil can improve filtration

Maintenance:

- Conduct routine periodic maintenance that is required of any grassed area: mow, weed, water, aerate and reseed.
- Maintain grass height equal or greater to the design flow depth.
- Minimize or eliminate us of fertilizers, herbicides, and pesticides.
- Remove sediment and debris after severe storm events.
- Inspect swales (and check dams) for erosion and repair and reseed as needed.

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

Any volume of stormwater in excess of the WQV can be detained by providing additional ponding and/or subsurface storage in the swale, thereby reducing the runoff volume and peak discharge rate. The voids in the soil and gravel layers provide stormwater storage capacity.

The depth of the gravel layer may be increased to add additional storage. Exfiltration into the subsoil can potentially reduce the volume of stormwater that ultimately enters the conveyance system.

Volume reduction depends on:

- available detention storage in the gravel layer and ponding area,
- the maximum flow rate into the subsoil,
- the flow rate into the swale,
  - storm intensity
  - drainage area size.

The cross-section of a water quality swale can be sized to provide conveyance for any given design storm, as required.

Water Quality Controls

Phosphorus removal efficiency is 15 percent if existing subsoil underlies the swale. However, the rate is 35 percent if an engineered soil mixture is used. Pollutant load reductions are achieved due to decreased volume of stormwater runoff.

Pollutant removal occurs in grassed swales through two mechanisms. Vegetation in the channel removes large and coarse particulates and sediment from stormwater. Pollutants are also removed by aerobic decomposition and chemical precipitation that occurs within the soil matrix while stormwater is infiltrating.

Location

Grassed swales should only be used where soils have infiltration rates of more than 0.3 inches per hour. Suitability of grassed swales depends on soil type, slope, imperviousness of the contributing watershed, dimensions and slope of the grassed swale system.

In general, grassed swales can be used to manage runoff from drainage areas that are less than 10 acres in size (although smaller areas are recommended), with slopes 5 percent or less, or velocities greater than 3 to 4 feet per second.

Grassed Swale
Source: VA DCR
PERMISSION PENDING

Cost

The cost for a water quality swale to treat runoff from ½ impervious acre consists of both the installation and annualized costs.

Cost calculations were based upon a water quality swale with a surface area of 900 square feet.

A water quality swale is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Swale capacity should be able to accommodate the peak flow from the design storm. Soil Conservation Service (USDA-SCS) hydrologic group A and B soils are required for grassed swales unless a permeability rate of 0.27 inches per hour or greater can be achieved. Soil amendments can be used to increase permeability.

The side slopes of the swale shall be no steeper than 3:1(rise:run) and longitudinal slopes shall be 5 percent or less. Check dams may be used to increase the overall detention time provided by the system.

Grass should be selected and installed in order to ensure swale stability and to provide sufficient surface roughness and filtering. Grassed swales typically consist of the component listed below.

Item	Unit	Estimated unit cost (2005 Dollars)
Grading	S.Y.	$0.10 - $0.15
Erosion control material	S.Y.	$1 - $2
Sod	S.F.	$2 - $4
Grass seed	S.F.	$1 - $2

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	...	25
Installation[1]	6,000												
Mowing		100	100	100	100	100	100	100	100	100	100		
Reseeding		50	50	50	50	50	50	50	50	50	50		
Aeration		50	50	50	50	50	50	50	50	50	50		
Remove & Replace													6,000
Total Cost	6,000	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**		**6,000**
Annualized Cost	$425 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

Maintenance activities include periodic mowing (grass must be cut equal to or higher than the design flow depth), weed control, watering during drought conditions, reseeding of bare areas, and clearing of debris and blockages. Significant storm events can cause sediment to accumulate. Swales must be inspected regularly for signs of erosion (especially at the edges of check dams) and for sediment deposition.

Minimize or avoid using fertilizers and pesticides. Fertilizers should only be used to aid required reseeding. Grass cover should be thick and reseeded as necessary. Periodically, swales should be aerated and debris should be removed. Vehicular traffic or parking must not be allowed on or around swales to avoid compacting soils.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)

Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/OW-OWM.html/mtb/vegswale.pdf

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

United States Environmental Protection Agency, 2000: Bioretention applications: Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. Office of Water, Washington, D.C., EPA-841-B-00-005A

U.S. Environmental Protection Agency, 1995: Maryland developer grows 'Rain Gardens' to control residential runoff. Nonpoint Source News-Notes, 42 (August/September)
http://www.epa.gov/NewsNotes/issue42/urbrnf.html

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is being conveyed through the entire water quality swale. Water standing in a water quality swale for more than 24 hours indicates operational problems.

If excessive ponding is observed, a swale should be inspected for any accumulated sediments. Any blockages should be removed.

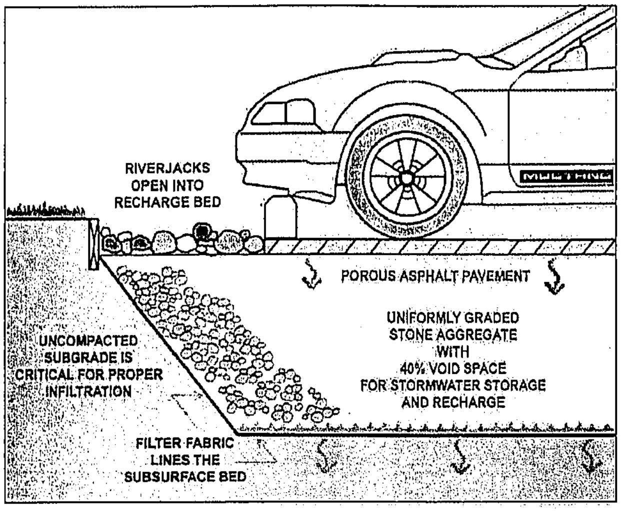
Aeration of a swale should be done every other year to maintain the function of the soils and aid infiltration. Annual inspections should be conducted to determine water infiltration and conveyance.

Reseeding or resodding may be required if the grass becomes diseased or damaged.

Perform inspection:

- annually in spring
- after severe weather events (e.g. hurricanes)

VIII.7.Permeable / Porous Pavement



Permeable pavement cross-section
Source: Cahill and Associates

Design Criteria:

- Asphalt or concrete with reduced fines and a special binder allowing water to pass through voids OR paving blocks installed with gaps between units that are filled with aggregate or soil and turf grass
- Porous paving is underlain with a subbase of aggregate comprised two layers:
  - Upper layer – fines
  - Lower layer – coarse aggregate
    - structural support
    - reservoir
- Geotextile fabric separates aggregate layers from the soil below
- Underdrains and cleanouts may be needed where infiltration rates are low

Maintenance:

- Primary Goal –
  Prevent clogging of voids by fine sediment particles
  - Vacuum pavement three (3) to four (4) times annually
  - DO NOT pressure wash pavement (forces particles deep into voids)
  - DO NOT apply abrasive materials as treatment for snow/ice safety hazards
- Inspect regularly for clogging as well as structural soundness.

Advantages:

- Useful in parking lots, driveways, road shoulders and paths
- Uses site features that cause stormwater management problems as part of a creative solution
- Conserves space allocated to storm-water management
- Effective for retrofit
- Enhance quality of downstream waters by decreasing runoff volume and peak discharge, as well as filtering pollutants and aiding recharge of groundwater

Disadvantages:

- Only feasible in areas level enough for vehicular and pedestrian uses
- Without adequate training, personnel can permanently damage structures
- Not feasible where sediment loads can not be controlled
- Not appropriate where the seasonal groundwater table – or bedrock - is within two (2) to four (4) feet of the bottom of the infiltration trench

A008150

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quality Controls

Pollutant loads can be cut by decreasing stormwater volume discharged through the subbase aggregate and by increasing infiltration into substrate. The first method of calculating load reduction is to calculate the volume of stormwater retained in the aggregate subbase. Further reduction of pollutant loads requires analysis of other pollutant removal mechanisms.

If stormwater is able to infiltrate into the soil, pollutants will further adsorb and be absorbed by soil particles. Other processes such as aerobic decomposition and chemical precipitation will also decrease pollutants within the soil matrix. Sand layers below the aggregate may provide water quality treatment.

A determination of pollutant load reductions will require an analysis of adsorption and absorption rates for soluble pollutants as well as rates of decomposition and precipitation.

Reductions in particulates and suspended solids can be achieved by physical removal when filtering through subbase aggregate.

Nitrogen removals depend greatly upon stormwater infiltrating into the soil where microbial conversion of nitrogen is able to occur.

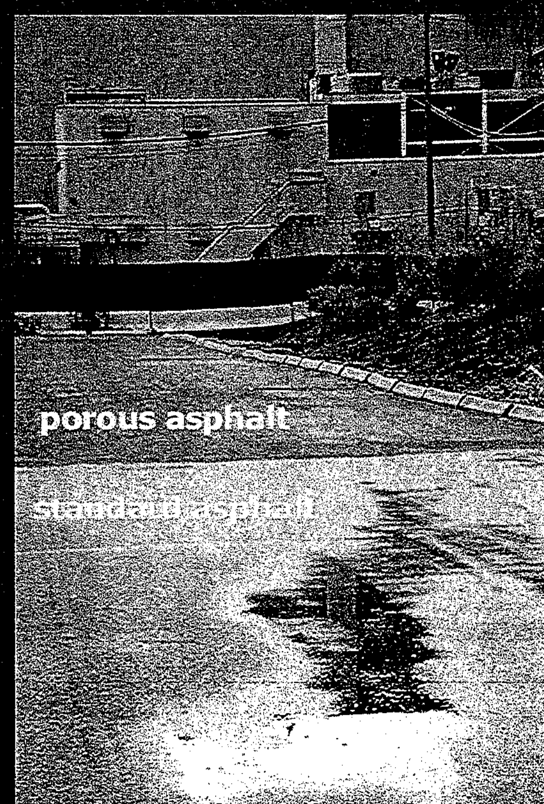
Water Quantity Controls

Porous pavements reduce stormwater runoff volume and peak discharge rates by providing a storage reservoir and an opportunity for subsurface infiltration. Stormwater volumes greater than WQV potentially can be stored.

Determining the reduction in stormwater volume requires determining the flow rate through the pavement, the response to the storm event, the volumetric storage area in the aggregate subbase, and the release rate. The interstitial voids provide stormwater storage. Permeability of surrounding soils adds storage capacity based upon infiltration rate. The depth of the aggregate subbase may be increased to add additional storage. The maximum depth of the aggregate subbase will be a function of the retention time desired, porosity of the selected aggregate, and soil infiltration rate.

Location

Permeable pavements may be used for parking lots, driveways, road shoulders and pedestrian paths. Such paving should not be used in areas with the potential for spills, such as gas stations or loading docks. Permeable pavement should not be used for roadways with traffic heavier or more frequent than that on residential roads.



Drainage in both types of pavement
Source: Cahill and Associates

Cost

The cost for porous or permeable pavement to treat runoff from ½ impervious acre consists of installation and annualized costs. Cost calculations were based upon permeable pavement being installed on 10% of a ½ acre parking lot.

Permeable pavement is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Construction of permeable asphalt and concrete will be similar to that of conventional pavements. Installation of paving blocks may require additional labor costs for hand placement. Similar materials and construction techniques are required for permeable and conventional pavements.

The largest difference is the depth of the aggregate subbase and the addition of the geotextile material. Permeable pavement systems typically consist of the following components.

Perforated underdrains may be used when constructing permeable pavement in areas where soil infiltration rates are low. Observation/cleanout wells must be installed if underdrains are used.
A clearance of at least two (2) to four (4) feet must be maintained between the bottom of the infiltration trench and the seasonal high groundwater table or bedrock, depending on site conditions.

Preventing overland runoff from flowing across permeable paving decreases sediment loading and maximizes lifespan and performance of the paving. This can be accomplished through the use of a perimeter berm or filter strip.

Item	Unit	Estimate unit cost (2005 dollars)
Excavation	C.Y.	$8 - $10
Porous asphalt	S.F.	$0.50 - $1.00
Porous concrete	S.F.	$2.00 - $6.50
Concrete paving blocks	S.F.	$5 - $10
Aggregate	C.Y.	$30 - $35
Geotextile fabric	S.F.	$0.70 - $1.00

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	...	25
Installation[1]	12,000												
Vacuum Sediment		500	500	500	500	500	500	500	500	500	500		
Remove & Replace													12,000
Total Cost	12,000	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**		**12,000**
Annualized Cost	$950 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

The main goal of a maintenance program for porous or permeable paving surfaces is to prevent clogging by fine sediment particles. Vacuum the pavement three (3) to four (4) times annually, depending on the average sediment loading.

DO NOT pressure wash the permeable/porous pavements, as this may force particles deeper into the pavement where it can no longer be removed by vacuuming.

Abrasive materials for snow treatment, such as sand, should be prohibited in order to prevent clogging of paving voids. Settlement of paving block systems may require resetting. Cracks and settlement in asphalt or concrete may require cutting and replacing the pavement section.

Potential LEED Credits

Primary: Sustainable Sites – Credit 7.1 "Landscape & Exterior Design to Reduce Heat Islands" (1 Point)
Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/owow/nps/pavements.pdf

LID Urban Design Tools
http://www.lid-stormwater.net/permeable_pavers/permpavers_benefits.htm

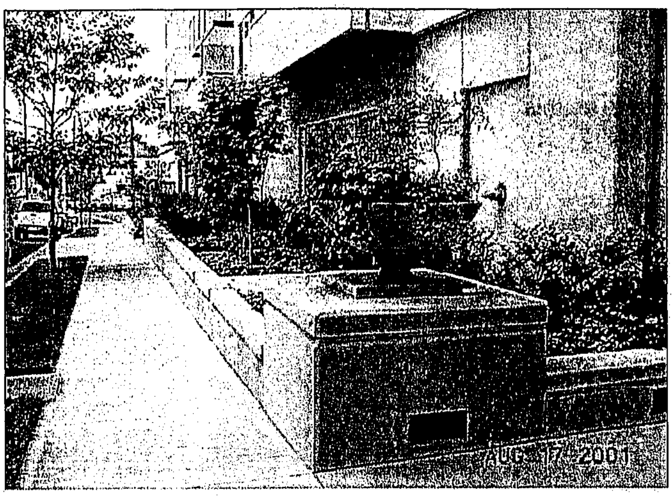
Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly and is not ponding on the surface of the porous or permeable pavement.

Standing water on such pavement may indicate clogging of open void spaces. Annual visual inspections should be conducted to check for accumulated sediments.

Routine vacuuming should prevent clogging. If voids are clogged, vacuuming is necessary.
If this treatment does not restore permeability, the pavement might be clogged beyond repair and may need to be replaced.

VIII.8.Planter Box



Planter Box
Source: LID Center

Design Criteria:

- Elevated structures intercept, store and filter stormwater from routed downspouts
- Planter boxes are constructed of materials capable of containing runoff and echoing the environment; the architecture and/or streetscape
- Planter boxes contain:
  - aggregate substrate
  - soil matrix
  - mulch
  - herbaceous plants, shrubs and/or small trees
- Underdrains and observation wells are recommended to avoid overflow in the event of heavy wet weather

Maintenance:

- Inspect planter boxes for structural integrity and clogging on a regular basis
- Backflush the underdrain in the event that obstructions are found during inspection
- Inspect the soil matrix and aggregate substrate to evaluate root growth and to verify channel formation is not occurring
- Turn or till soil matrix if infiltration becomes slowed due to soil compaction
- Identify damaged components and repair or replace, if needed.

Advantages:

- Effective as part of an overall disconnection strategy in urban areas
- Provide capacity to store and filter runoff
- Enhance quality of downstream water bodies
- Offer "green space" in densely developed environments
- Stormwater provides resources to plantings effectively at low cost enhancing viability
- Effective for retrofit

Disadvantages:

- Space needed for planter boxes may not be available in all situations within the urban environments where they are most cost effective
- High attrition rates for plantings in stressful urban settings may necessitate vigilant maintenance and higher costs than less complex alternatives such as cisterns

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quality Controls

Water quality benefits are similar to those for bioretention cells. Phosphorus removal is achieved at the rate of 50 percent for the first one-half inch (0.5") of runoff that enters the planter box from impervious areas.

Planter boxes contribute to pollutant load reductions by minimizing the volume of stormwater generated. Rainfall is retained and stored in the special soil matrix and substrate. Rainfall is intercepted by plants which evapo-transpire moisture.

Concentrations of pollutants will also be reduced as stormwater infiltrates through planter box soil. Pollutants adsorb and are absorbed by the soil particles. Aerobic decomposition and chemical precipitation will also decrease concentrations of pollutants within the soil matrix.

Determination of pollutant load reductions requires an analysis of adsorption and absorption rates for soluble pollutants, as well as decomposition and precipitation rates.

Reductions of suspended solids and particulates are achieved by physical removal when runoff is filtered through the aggregate.

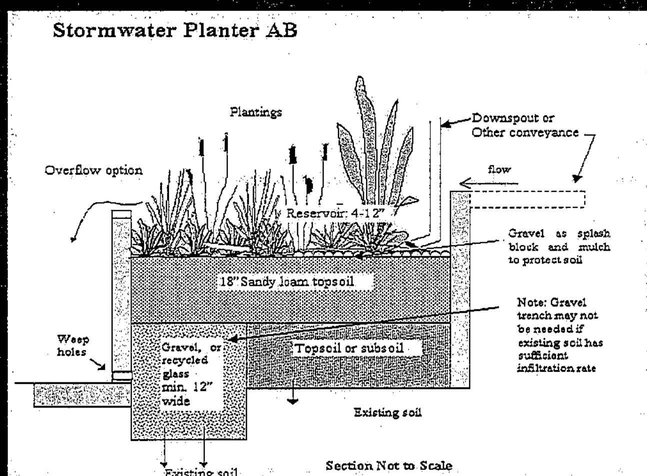
Water Quantity Controls

Routing stormwater to planter boxes can reduce runoff volume and the rate of peak discharge by providing temporary ponding capacity, in addition to sub-surface soil storage.

Additional storage can be provided by constructing a gravel storage bed below the planting soil, similar to gravel layers in bioretention cells.

Location

Planter boxes are most commonly used in urban areas adjacent to buildings and along sidewalks. Locations close to roof downspouts are preferable when used as part of a downspout disconnection program.



Planter Box Schematic
Source: LID Center

A008155

Cost

The cost for a planter box system to treat runoff from ½ impervious acre is comprised of both installation cost and annualized costs. These calculations were based upon a planter box system with a total surface area of 500 ft^2.

A planter box is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Planter boxes may be constructed of any durable material. When abutting a building, planter boxes are often made from materials used in the building's construction. They also might be constructed of concrete or other materials used in the nearby streetscape. Stand-alone units might be metal or fiberglass, or other appropriate materials.

An appropriate soil mix is needed to ensure adequate plant growth and vitality. Native plants are often preferred in order to maximize plant viability and to ease maintenance.

Underdrains can be installed to connect planter boxes to a runoff conveyance system. Observation/ clean-out wells should be installed if underdrains are used.

Item	Unit	Estimated unit cost (2005 Dollars)
Planter box construction (concrete)	C.Y.	$75 - $125
Vegetation planting	Ea.	$5 - $20
Soil media	C.Y.	$15 - $25
Underdrain - perforated pipe (4" dia.)	L.F.	$8 - $12

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	...	25
Installation[1]	4,000												
Mulching, Weeding, and Debris Removal		300	300	300	300	300	300	300	300	300	300		
Replace Vegetation		100	100	100	100	100	100	100	100	100	100		
Concrete Repair						500					500		
Remove & Replace													4,000
Total Cost	4,000	**400**	**400**	**400**	**400**	**900**	**400**	**400**	**400**	**400**	**900**		**4,000**
Annualized Cost	$625/ year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

Maintenance activities entail routine inspections of the planter box structure and the underdrain. Soil matrix and substrate also need to be inspected to evaluate root growth and channel formation.

The soil media may need to be tilled to improve infiltration. Plants may need to be replaced. Back-flushing the underdrain may be able to remove obstructions. If these efforts are unsuccessful, the soil media and underdrain may need to be removed and replaced.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Other: Water Efficiency – Credit 3 "Water Use Reduction" (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Additional Information

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

Achieving Sustainable Site Design through Low Impact Development Practices, Whole Building Design Guide
http://www.wbdg.org/design/lidsitedesign.php

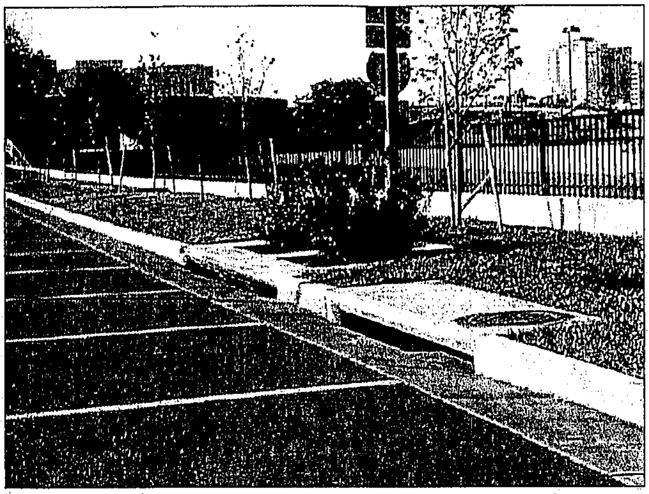
Planter Boxes - City of Sandy Oregon
http://www.ci.sandy.or.us/pw/Storm/Planter_boxes.htm

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly into the planter box soil matrix and that there is discharge from the underdrain during heavy wet weather events. Ponding of rainwater in a planter box for more than 24 hours indicates operational problems.

If excessive ponding is observed, corrective measures include inspecting the soil matrix for signs of compaction, as well as the underdrain for signs of clogging.

VIII.9.Tree Box Filters



Tree box filter at the Pentagon
Source: LID Center

Design Criteria:

- Tree box filters resemble typical urban street tree planters are installed below grade along a curb line. They consists of:
  - A pre-cast concrete box
  - Bioretention soil or growth media
  - A tree or shrub
- A standard curb inlet is set downstream from tree box filters. High volumes of stormwater will bypass the tree box filter, if full, and flow directly to the inlet.
- Plants should be selected based on local recommendations for street trees highly tolerant of high stress conditions. Natives are preferred.

Maintenance:

- Periodic, regular removal of trash and debris is required, preferably at least seasonally and after severe storm events
- Replenishment of the mulch layer is recommended once or twice annually.
- Inspect the tree box regularly for clogging and flush via the cleanout, if needed.
- During extreme droughts, water the tree or shrub just as any other landscape plants.

Advantages:

- **Provide shade and shelter, absorb noise, filter air pollutants and improve the aesthetic value of urban landscapes**
- **Effective for retrofit**
- **Enhance quality of downstream waters**
- **Relatively small units can treat large areas (comparatively) and their runoff volumes**

Disadvantages:

- **Among LID practices and technology, tree box filters are one of the more expensive alternatives**
- **Tree box filters are effective for capture of the WQV (water quality volume) for only small, frequently occurring storms --- they cannot handle larger volumes, nor can they detain WQV for extended periods**
- **Additional storage systems are required downstream for large flow volumes --- with added installation and upkeep costs**

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

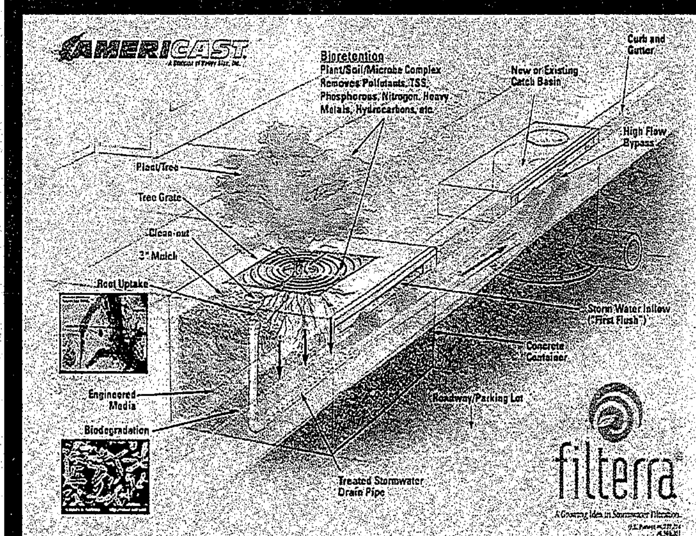
Tree box filters can reduce the runoff volume and peak discharge rate for small, frequently-occurring storms by capturing the water quality volume (WQV). They are not intended to capture volumes larger than the WQV, or to detain the WQV for extended periods of time. Volumes larger than the WQV can be detained in a subsurface storage system downstream — such as a gravel bed.

Water Quality Controls

Tree box filters remove pollutants through the same biological, chemical, and physical mechanisms as bioretention cells.

Pollutant	Expected removal
Total suspended solids	85%
Total phosphorous	74%
Total nitrogen	68%
Total metals	82%

Source: Virginia Stormwater Minimum Standard 3.11C



Tree box filter schematic
Source: Americast
PERMISSION PENDING

Location

Tree box filters can receive stormwater runoff from streets and parking lots, as long as a downstream inlet or outfall is present. All land uses are suitable.

Cost

The cost for a tree box filter to treat runoff from ½ impervious acre is comprised of both the installation cost and annualized costs. These cost calculations were based upon installing two (2) 6' x 6' tree box filters.

A tree box filter is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

A tree box filter this size costs approximately $8,000, including two (2) years of maintenance, filter material, and plants. Installation costs about $1500 per unit for a total of $9500.

Annual maintenance is $500 per unit when performed by the manufacturer, but only $100 per unit if tended by the owner/operator.

Design Construction and Materials

To treat 90 percent of the annual runoff volume, the surface area of a tree box filter should be approximately 0.33 percent of the drainage area. Tree boxes must be regularly spaced along the length of a corridor to meet the annual treatment target. A curb inlet must be located downstream of the tree fox filter(s) to intercept bypass flow.

Tree box filters are off-line devices and should never be placed in a sump position (i.e. at a low point). Instead, runoff should flow *across* the inlet. Also, tree box filters are intended for intermittent flows and must not be used as larger event detention devices.

Tree box filters consist of a pre-cast concrete container, a mulch layer, bioretention media, observation and cleanout pipes, underdrain pipes, and a single tree or large shrub. A decorative grate is typically used to protect the device and the plant, as well as to intercept large debris. Pretreatment under normal conditions is not necessary.

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	...	25
Installation[1]	19,000												
Mulching and Debris Removal		150	150	150	150	150	150	150	150	150	150		
Replace Vegetation						250					250		
Remove & Replace													19,000
Total Cost	19,000	**150**	**150**	**150**	**150**	**300**	**150**	**150**	**150**	**150**	**300**		**19,000**
Annualized Cost	$950 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

Maintenance of tree box filters typically entails annual inspection and regular removal of trash and debris. Mulch will need to be replenished one (1) to two (2) times per year. The cleanout pipe can be used to flush the system if the underdrain becomes clogged.

During extreme droughts, the tree or shrub may need supplemental water just as any other landscape plants. In these high stress environments, plants may need to be replaced every few years (5 years is the interval assumed for this cost estimate).

Potential LEED Credits

Primary: N/A

Other: Innovation & Design Process (1-4 Points)

Links to Additional Information

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

Sizing of Tree Box Filters - LID Stormwater
http://www.lid-stormwater.net/treebox/treeboxfilter_sizing.htm

LID Technologies, Whole Building Design Guide
http://www.wbdg.org/design/lidtech.php

Americast Filterra
http://www.americastusa.com/filterra.html

Performance and Inspection

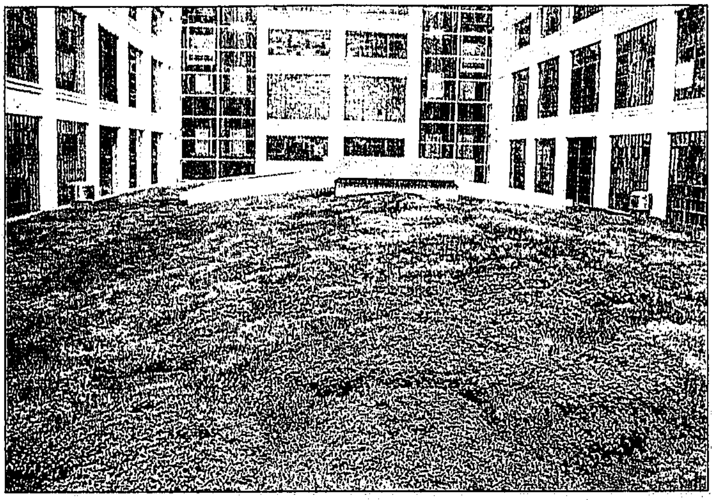
To ensure proper performance, visually inspect each tree box filter to verify that stormwater is infiltrating properly. Excessive volumes of stormwater bypassing a tree box filter may indicate operational problems.

Corrective measures to restore performance include further detailed inspection to uncover accumulated sediments and debris and, then, removal, if needed.

In instances where the condition of the soil media has significantly degraded, the media and vegetation should be removed and replaced.

Inspection and maintenance should occur on an annual or semi-annual basis.

VIII.10.Green Roofs



Extensive green roof in Baltimore, MD
Source: Katrin Scholz-Barth Consulting.

Design Criteria:

- Extensive green roofs are low profile and lightweight: thin sheaths of soils, mosses, sedums, herbs and other perennials
- Intensive green roofs use a greater depth of growth media and sturdier structures to support trees, shrubs and activity areas
- Green roofs consist of several layers:
    - Waterproof membrane*
    - Root barrier
    - Insulation layer
    - Drainage layer
    - Growth medium
    - Vegetation

**Leak detection is optional*

Maintenance:

- Properly installed green roofs require little upkeep beyond typical conventional roofs
- Periodic weeding, as well as soil and plant replenishment are the primary upkeep tasks for extensive green roofs
- Intensive green roofs require more structural as well as horticultural upkeep
- EFVM systems are recommended for intensive green roofs in case leaks need to be discovered and repaired
- Conditions of draught or high wind may require supplemental watering/irrigation

Advantages:

- **Reduce roof runoff volume**
- **Reduce runoff pollutant loads**
- **More durable than conventional roofs**
- ***Extensive* greenroofs are useful for retrofits**
- ***Intensive* greenroofs provide valuable urban open space**
- **Insulating properties absorb noise, reduce energy use/loss and ameliorate urban heat island effects --- resolving many urban issues simultaneously**

Disadvantages:

- **Among LID practices and technology, green roofs are one of the most expensive alternatives**
- **Designing green roofs requires uncommon professional expertise and additional design costs**
- **Maintenance of green roofs requires some degree of specialized training**

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

Green roofs store rainwater in their soil layer, reducing the volume and peak discharge rate of roof runoff. The storage capacity can be estimated using the equation below.
Equation 1:
*Storage volume = (green roof area) * (soil depth) * (soil porosity)*

This equation is based on the fundamental principle of soil porosity and provides a general guideline for estimating storage capacity. More complex calculations can be used for further detailed analysis.
Green roofs are generally sized to store the water quality volume (WQV):
the first 0.5" of rainfall.

Additional soil depth can be used to increase a green roof's storage capacity.

Part of the stormwater will be retained on the roof and lost to evapo-transpiration. Part of the stormwater will percolate through the drainage layer and become surface runoff. The water retention capacity of the soil medium is dependent upon both the properties of the medium and characteristics of the vegetative cover, as well as climactic conditions.

Water Quality Controls

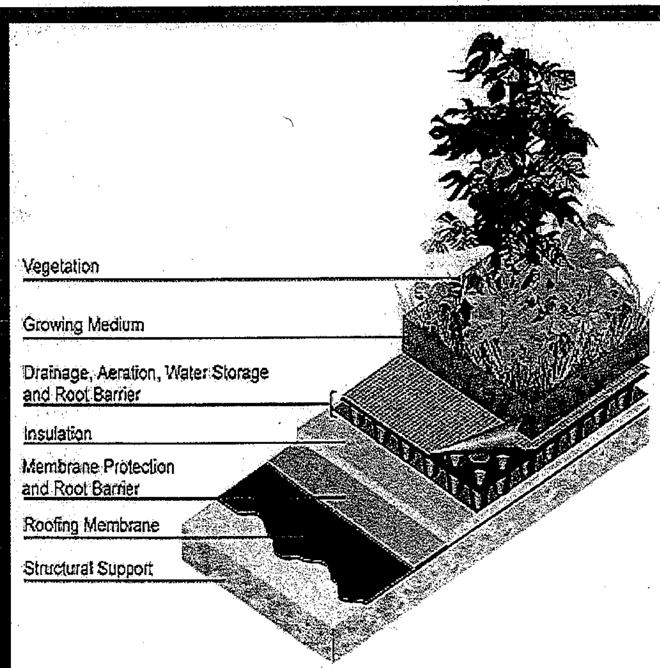
No conclusive water quality information can be presented at this time; research in this area is ongoing.

More Information:
Green Roofs for Healthy Cities
http://www.greenroofs.org/

Third Annual Greening Rooftops for Sustainable Communities Conference, Awards, & Trade Show, May 4th - 6th, 2005 - Washington, D.C.
http://www.greenroofs.org/washington/index.php

Location

Green roofs can be placed on any residential, commercial, or industrial roof surface that is not reserved for patio or utility access.



Extensive green roof cross-section
Source: American Wick Drain Corp.

Cost

Costs for ***extensive*** green roofs are $15 to $20 per square foot for all use types (e.g. high density residential or commercial/industrial). These costs include all green roof components, including waterproof membrane, growth medium, and plants.

The highest costs of green roof construction are the growth medium components and plants. Costs are higher if plants are placed individually rather than installed as vegetated mats.

Costs are given for an ***extensive*** green roof. The cost for a ½ acre (21780 ft^2) extensive green roof consists of both installation costs and annualized costs.

A green roof is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Green roofs consist of several layers. Beginning with the bottom layer, they consist of a waterproof membrane, a root barrier, an insulation layer, a drainage layer, growing medium, and vegetation. A drainage layer is needed for flat roofs but may not be necessary for sloped roofs. A leak detection system below the membrane is optional.

Deciding whether to construct an intensive or extensive roof may be influenced by the property owner's desired maintenance level and by the roof's structural capacity. Soil depth is another design variable and determines water storage capacity. Plants recommended for use on green roofs are hardy, self-sustaining, drought-resistant plants.

Often, plants of the Sedum and Delosperma (common succulents) genuses are used for extensive green roofs. Many species ane varieties are available from a wide array of vendors.

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	...	25
Installation[1]	250,000												
Weeding		500	500	500	500	500	500	500	500	500	500		
Infill with cuttings[2]						6000					6000		
Soil replenishment						1000					1000		
Remove & Replace													250,000
Total Cost	**250,000**	**500**	**500**	**500**	**500**	**7500**	**500**	**500**	**500**	**500**	**7500**		**250,000**
Annualized Cost	$11,600 / year (includes replacement in year 25). Excluding replacement: $1,600 / year												

[1]Developer Cost. Not included in annualized cost.
[2]Assume 5% of area needs replanting, and a density of 2 plugs per square foot.

Maintenance

Once a properly installed green roof is established, its maintenance requirements are generally minimal. The main requirements for ***extensive*** roofs are weeding, as well as periodic soil and plant replenishment. More structural and horticultural maintenance is required for ***intensive*** roofs because plantings are typically heavier and more elaborate.

Corrective actions for green roofs are generally localized repairs. Leaks need to be quickly repaired, if they should be detected. An electric leak survey (i.e. Electrical Field Vector Mapping) can be performed to locate leaks in the membrane. More complex green roof systems have monitoring devices installed with the waterproof membrane.
Long periods of drought or loss of soil to high winds may require replacement of growth media or replanting. If drought becomes an issue, corrective actions include installing an irrigation system or scheduling supplemental watering.

Potential LEED Credits

Primary: Sustainable Sites – Credit 7.2 "Landscape & Exterior Design to Reduce Heat Islands" (1 Point)
Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Links to Additional Information

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

Green Roofs for Healthy Cities
http://www.greenroofs.org/

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http://www.greenroofs.org/washington/index.php

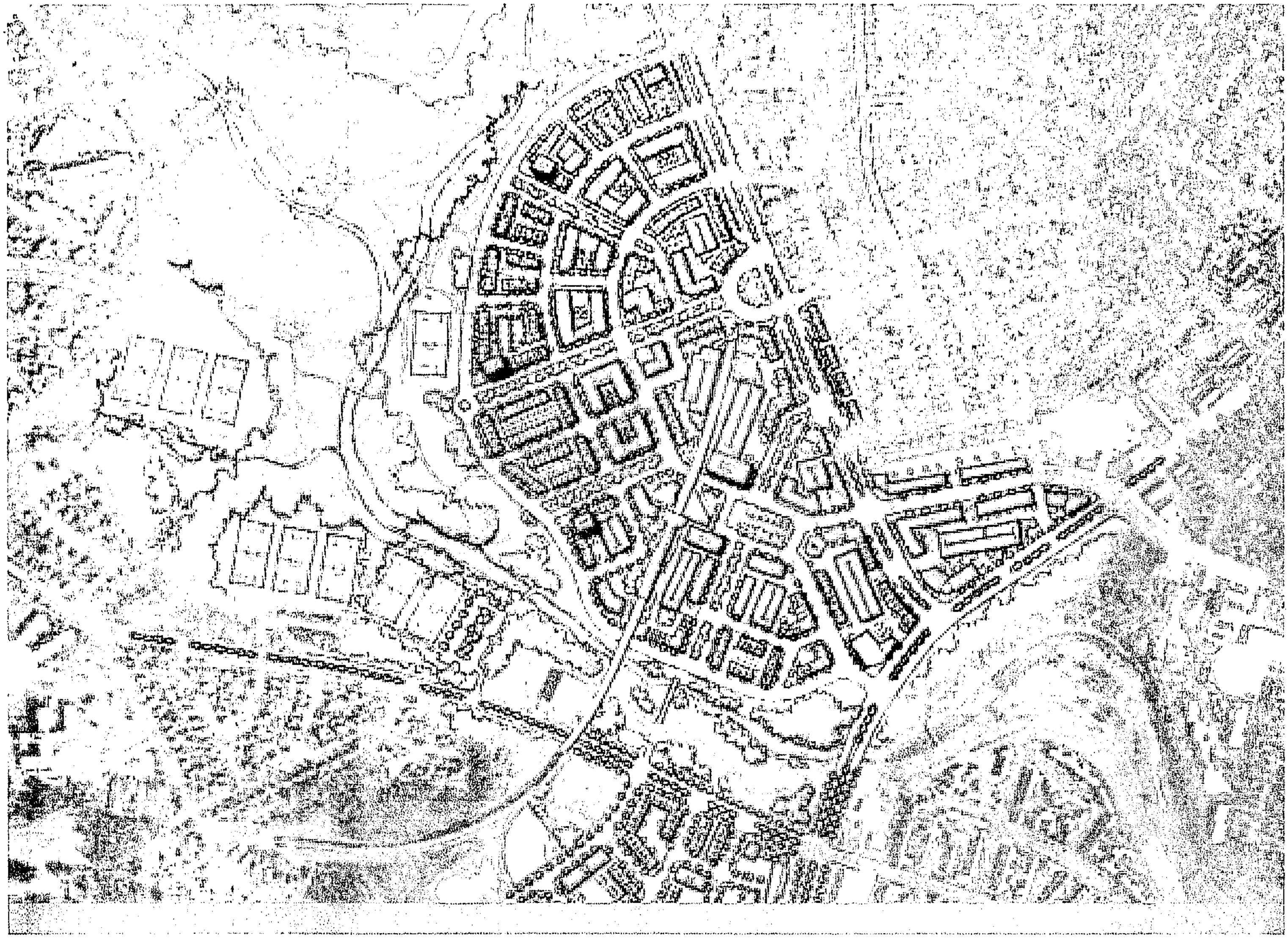
Resource Portal for Green Roofs
http://www.greenroofs.com/

Performance and Inspection

Soil stability and plant vitality are keys to the function of green roofs. Green roofs should be inspected annually for loss of growth medium due to erosion and to asssure plant health. However, wind or water erosion should not be a major concern because the plants' dense root structures provide stabilization. If any erosion should occur, add soil, replant, and install temporary erosion control fabric. Replace dead plants as needed.

Note: if slow-growing plants are selected, more than a single growing season may be needed to achieve full growth.

EPA United States Environmental Protection Agency



Using Smart Growth Techniques as Stormwater Best Management Practices

A008155

About the Image on the Cover

The cover illustration depicts development that might occur as a result of the recently updated West Hyattsville (Maryland) Transit Oriented Development Overlay Zone. This area is served by the Metrorail (subway) and is home to the West Hyattsville Green Line station. The elements of the plan include many common features of transit oriented development (TOD): a compact footprint, development intensity focused on the station area, a rich mix of uses and housing types, and a variety of transportation options. These features, as illustrated in this publication, also have benefits related to preventing and managing stormwater, in particular, when considered at the watershed, neighborhood, and site levels simultaneously. The compact design can accommodate a higher intensity of development on a smaller footprint. This format, oriented toward transit and pedestrian travel, also lessens the imperviousness related to automobile-only travel. By accommodating a higher intensity of development in this preferred area, demand that might go elsewhere in the undeveloped parts of the watershed is absorbed.

The West Hyattsville TOD Plan goes further to address water and stormwater throughout the planning area. There is a heavy emphasis on open space, active parks, and integrated stormwater management. In developing the plan, use of natural drainage patterns and habitat restoration were coupled with development of parks, fields, and trails.

Image courtesy of PB PlaceMaking and the Maryland National Capital Parks and Planning Commission - Prince George's County Planning Department.

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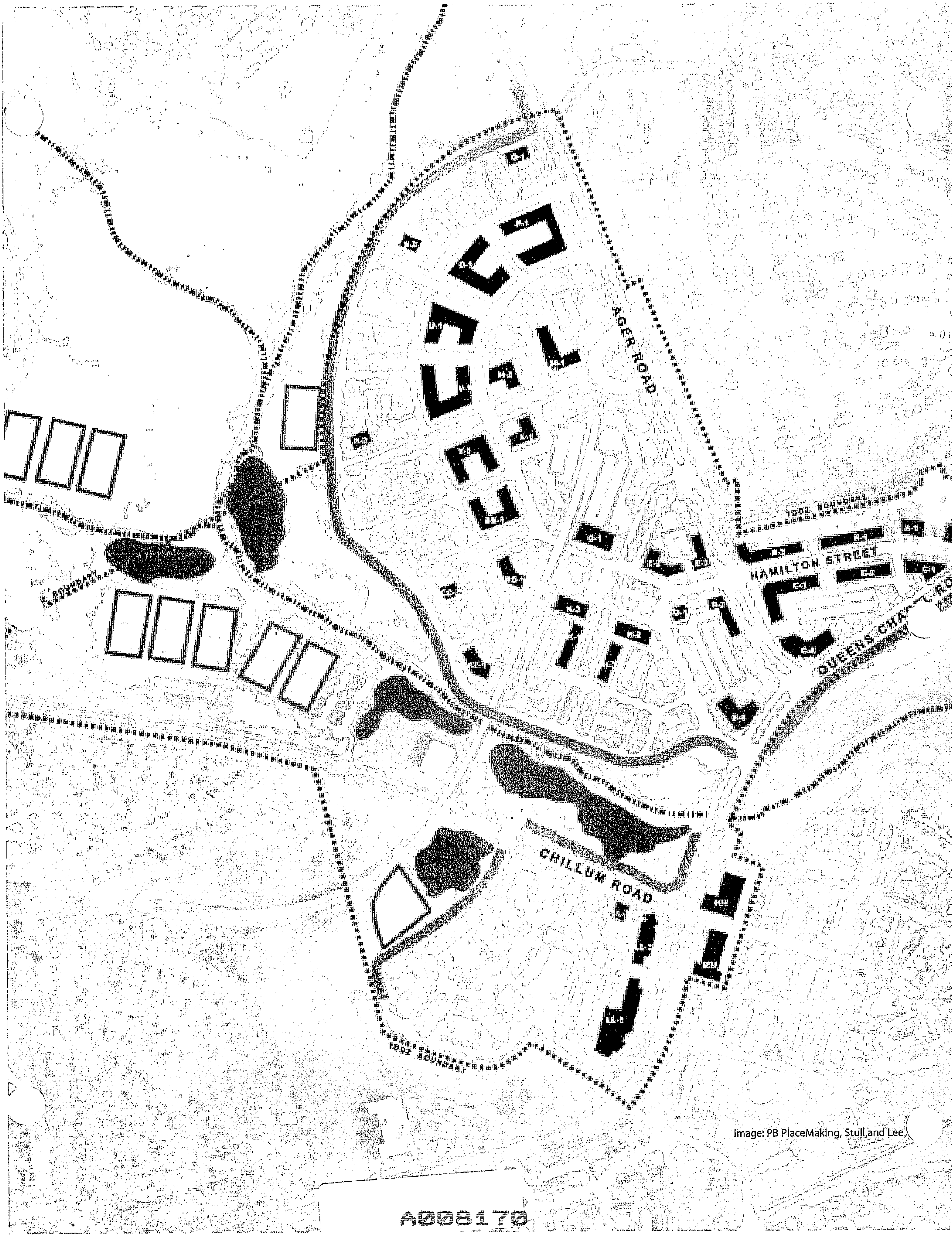

Image: PB PlaceMaking, Stull and Lee

EXECUTIVE SUMMARY

Communities around the country are adopting smart growth strategies to reach environmental, community, and economic goals. The environmental goals include water benefits that accrue when development strategies use compact development forms, a mix of uses, better use of existing infrastructure, and preservation of critical environmental areas. While the water quality and stormwater benefits of smart growth are widely acknowledged, there has been little explicit regulatory recognition of these benefits to date.

Regulations under the National Pollutant Discharge Elimination System (NPDES) stormwater program offer a structure for considering the water quality benefits associated with smart growth techniques. Compliance with federal, state, and local stormwater programs revolves around the use of "best management practices" (BMPs) to manage stormwater. Given the water benefits of smart growth at the site, neighborhood, and watershed levels, many smart growth techniques and policies are emerging as BMPs.

The goal of this document is to help communities that have adopted smart growth policies and plans recognize the water benefits of those smart growth techniques and suggest ways to integrate those policies into stormwater planning and compliance. Taking credit for the work a community is already doing can be a low-cost and practical approach to meeting water quality goals and regulatory commitments.

This document is related to a series of primers on smart growth. In 1999 and 2001, the International City/County Managers Association (ICMA) and the U.S. Environmental Protection Agency (EPA) released two primers that each listed 100 smart growth policies. In 2004, EPA released *Protecting Water Resources with Smart Growth*, which presented 75 policies directly related to water resources. This document also complements the EPA's National Management Measures to Control Nonpoint Source Pollution from Urban Areas (2005).

Who Can Use This Report?

Stormwater and Water Quality Professionals: This document is written to help water professionals understand urban planning documents to determine where stormwater improvements might already be included. This document can also be helpful to consultants who are helping communities develop comprehensive stormwater and planning documents, outreach programs, and compliance tracking.

Communities Regulated Under Phases I & II of the NPDES Stormwater Program: More than 6,000 communities are now required to develop stormwater management plans to comply with the NPDES requirements. As NPDES permits issued since 1990 under Phase I come up for renewal, this document offers innovative measures for further improving stormwater management through redevelopment, infill, urban parks, and green building techniques. Communities under Phase II are likely to be developing their stormwater management plans, guidance materials, and ordinances.

Local Land Use and Transportation Planners: Just as stormwater engineers are taking on more of an urban planning role, land use and transportation planners should consider the practice of stormwater control in ways that go beyond pipes, ponds, and gutters. This document introduces the concept of joint land use, transportation, and water planning as a way of providing water quality protection and satisfying regulatory commitments for compliance with local stormwater management plans and NPDES permits.

Zoning Administrators: Language in many federal and state model stormwater ordinances call for the development of "ordinances or other regulatory mechanisms" for implementation of new stormwater rules.

Most stormwater that is collected from curbs and gutters flows untreated into local waterways. Smart growth seeks to limit the number of outfalls in a watershed with compact development.

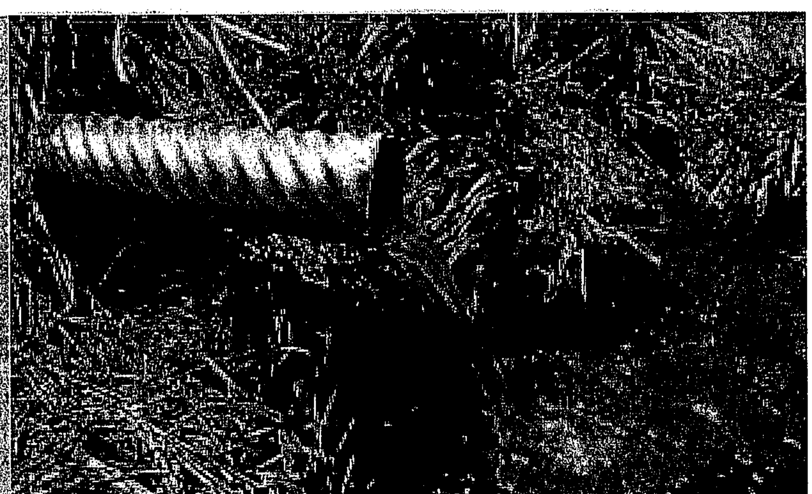

Photo: NRCS

The elements related to stormwater ordinances are likely to address the same aspects of project design as zoning codes, for example, setbacks, street widths, landscaping and parking requirements. Zoning administrators should be involved in the development of stormwater ordinances so that conflicts do not arise among codes.

City and County Managers: The stormwater requirements have focused attention on improving communications across various departments, from public works to transportation to subdivision planning. As new and revised stormwater rules are written at the local level, NPDES implementation has revealed the importance of pulling together traditionally autonomous departments to determine where separate departmental policies might pose barriers to efficient planning, investment, and environmental protection. City and county managers are often in a unique position to bridge planning and budgets and broker solutions where requirements developed by one department run counter to new smart growth plans.

Developers: Developers, particularly those building within urbanized areas affected by NPDES stormwater rules, are facing new requirements for water quality and quantity. This document will help developers assess their smart growth projects, improve the stormwater handling on site, and define how their projects meet stormwater goals and the site, neighborhood, and regional level.

Smart Growth Practitioners: Whether you are with a nonprofit organization, a local government office, or in private practice, your skills in reviewing and writing comprehensive environmental plans and policies can play a role in shaping joint smart growth and stormwater plans. Emerging stormwater programs offer a framework for constructive involvement.

Talking About Compact Development – Homebuilders

In 2005, the National Association of Homebuilders (NAHB) released talking points on compact development. They note that compact forms can include cluster development, higher-density development, mixed-used projects and traditional neighborhood developments. The Association encourages builders to review local ordinances to see where rules on set backs, infrastructure, street widths and the approval processes pose barriers or opportunities for compact development. In particular, the talking points mention alternative stormwater approaches to help support a more compact development form.
See <www.nahb.org/generic.aspx?sectionID=628&genericContentID=17373>.

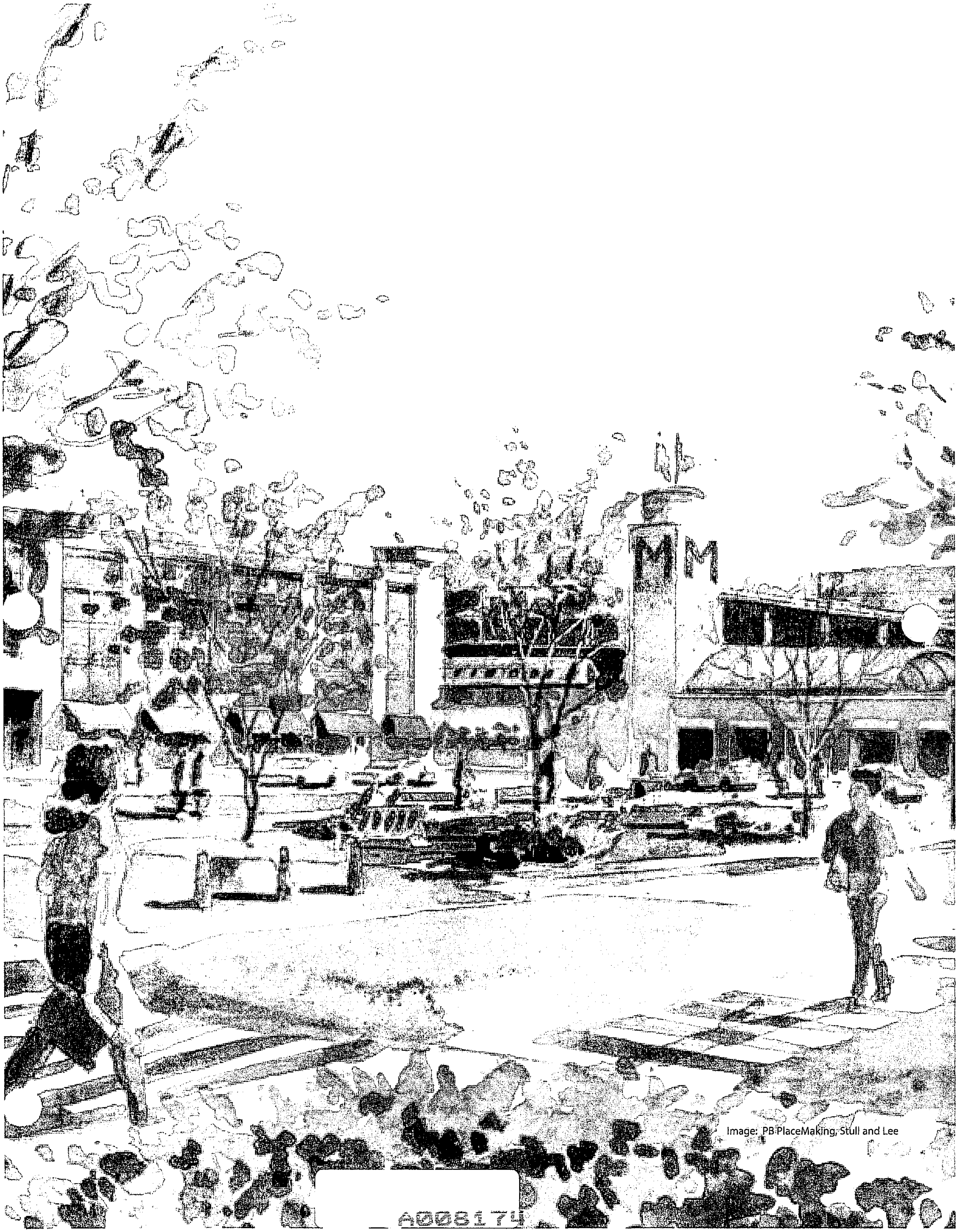

Image: PB PlaceMaking, Stull and Lee

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SECTION 1

Why Stormwater? The Nexus Between Land Development Patterns and Water Quality and Quantity

Since 1972, implementation of the Clean Water Act (CWA) has shown success in controlling water pollution from point sources such as municipal wastewater treatment plants and industrial discharges. This progress is overshadowed, however, by the emergence of nonpoint source pollution as a main contributor to water quality problems.

Nonpoint source (NPS) pollution comes from many diffuse sources. NPS pollution originates when rainfall or snowmelt moves over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even underground sources of drinking water.

These pollutants include:

- Excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas.
- Oil, grease, and toxic chemicals from urban runoff.
- Sediment from improperly managed construction sites, crop and forest lands, and eroding stream banks.
- Bacteria and nutrients from livestock, pet wastes, wildlife, and faulty septic systems.
- A myriad of other pollutants originating with a side variety of land based activities.
- Atmospheric deposition and hydromodification are also sources of nonpoint source pollution.[1]

For urban and urbanizing areas, these problems can largely be traced to activities that occur on the land. Whether the problem arises from lawn care chemicals, or motor oil and toxic metals from parking lots and streets, stormwater plays a large role in transporting pollutants to streams, drinking water sources, and other receiving water bodies.

While land development necessarily involves creation of impervious surfaces, how and where development takes place can influence the ultimate degree of environmental impact from the streets, rooftops, and yards. Where development has occurred on forest and undeveloped land, critical areas for infiltration and aquifer recharge that soaked up rainwater prior to development now export runoff to lower lying areas and local receiving water bodies. Water flowing over pavement absorbs heat, which impacts waterways that support cold water species. It also flows faster, thus delivering water in pulses. The faster flows can scour stream banks and accelerate erosion, while increased temperatures can spur excessive algal growth. The higher rate of vegetative growth can interfere with a variety of ecological, industrial and water filtration processes. Conventional construction practices have relied on mass clearing and grading. This practice compacts the soil surface and further prevents infiltration, even on lots overlain with turf. Thus, the generation of stormwater volume, as well as the pollutant load carried in that volume, is very much tied to how and where land is developed.

Preserving open space, farmland and critical environmental areas is one of the 10 smart growth principals.

Summary of How Stormwater Runoff Is Regulated

In 1972, Congress amended the Federal Water Pollution Control Act (subsequently referred to as the Clean Water Act) to control the discharges of pollutants to waters of the United States from point sources. Initial efforts to improve water quality using the National Pollution Discharge Elimination System (NPDES) focused primarily on reducing pollutants from industrial process wastewater and municipal sewage discharges. These sources were easily identified as responsible for poor—often drastically degraded—water quality conditions.

As pollution control measures for industrial process wastewater and municipal sewage were implemented and refined, it became increasingly evident that more diffuse sources of water pollution were also significant causes of water quality impairment. Specifically, stormwater runoff was found to cause serious pollution problems. As a result Congress added section 402(p) of the Clean Water Act, which established a comprehensive, two-phase approach to stormwater control using the NPDES program.

In 1990 EPA issued the Phase I stormwater rule (55 *FR* 47990; November 16, 1990) requiring NPDES permits for operators of municipal separate storm sewer systems (MS4s) serving populations greater than 100,000 and for runoff associated with industrial activity, including runoff from construction sites 5 acres and larger. In 1999 EPA issued the Phase II stormwater rule (64 *FR* 68722; December 8, 1999) that expanded the requirements to small MS4s in urban areas and to construction sites between 1 and 5 acres in size.

EPA has delegated NPDES permitting authority to all but five states, several territories, the District of Columbia, federal facilities in four states, and federal tribes. NPDES permits are reissued every five years to allow for modifications to meet changing conditions both with the discharge and with discharge standards and regulations. There are two standard types of NPDES permits: 1) An individual permit is issued to a single discharger, with customized requirements for that particular discharge. All Phase I MS4 permits are individual permits. 2) General permits are usually statewide permits with requirements that apply to all discharges of a particular type or category. Most Phase II MS4 permits are general permits and require each permittee to develop a stormwater management plan that details how stormwater discharges from that particular MS4 will be controlled. Though they are not framed identically, the stormwater management requirements for Phase I and Phase II MS4s are very similar. The recommendations in this publication are applicable to all communities subject to the stormwater regulations.

Evaluations of Phase I have shown that BMP maintenance continues to be a problem.[2] Both structural BMPs (e.g., sand filters) and nonstructural BMPs (e.g., swales) require periodic maintenance and care, which should be budgeted for and scheduled. As you read this document, think about the long-term maintenance program for smart growth techniques as BMPs to ensure that stormwater benefits are supported over time.

To learn more, visit EPA's stormwater program site at <www.epa.gov/npdes>.

What Is an MS4?

A municipal separate storm sewer system (MS4) is a conveyance or system of conveyances (e.g., roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, storm drains) that are:

- Owned or operated by a state, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to state law) having jurisdiction over disposal of sewage, industrial wastes, stormwater, or other wastes, including special districts under state law such as a sewer district, flood control district, or drainage districts, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under section 208 of the Clean Water Act that discharges to waters of the United States.
- Designed or used for collecting or conveying stormwater.
- Not a combined sewer.
- Not part of a publicly owned treatment works.

Though not explicit, many larger institutions, such as hospitals, universities, military bases, and school districts fall under the definition, and thus must develop stormwater management plans. If these institutions have been involved with local smart growth efforts, check with them to see if there are smart growth elements in their stormwater management plan.

Elements of a NPDES Stormwater Permit – What Stakeholders Should Look For

States and municipalities are responsible for developing a suite of information under the NPDES stormwater program. As you look for the documents that will govern stormwater rules and policies, be aware that there are several permit types within the NPDES stormwater program, including industrial, multi-sector, and construction permits. While these are important permits for environmental protection, the MS4 NPDES stormwater permits are the focus of this document. Section 2 includes guidance on what to specifically look for within these materials.

At the Federal Level:

EPA has issued many guidance documents to assist states and localities. These publications include:

- Sample and General Permits
- Fact Sheets and Outreach Materials
- Permit Applications and Forms
- Policy and Guidance Documents
- Program Status Reports
- A Menu of Best Management Practices
- Technical and Issue Papers
- Case Studies
- See <http://cfpub.epa.gov/npdes/stormwater/swphases.cfm>. For information, go the link on "Publications."

At the State Level:

Under the NPDES program, delegated states are required to develop and implement stormwater management plans to reduce pollutant loadings to the maximum extent practicable. Delegated states oversee both Phase I and Phase II of the stormwater program, so plans may be listed as medium and large MS4s (Phase I) and small MS4s (Phase II). The Web site <www.stormwaterauthority.org> lists links to each state's MS4 stormwater program. The elements to look for include the following:

- **A state permit**: Most states have developed a General MS4 permit, which establishes minimum requirements for permit coverage. Some states have also developed alternatives to the general permit, such as watershed permitting, to allow for customization and innovation. The permit lists the elements required to obtain permit coverage, which typically include: time tables; the minimum components of a stormwater management plan; and legal language defining responsibilities, enforcement, and penalties.
- **Guidance documents:** These documents are developed to assist localities as they write their stormwater management plans and develop menus of BMPs.
- **State requirements:** Many states have additional requirements to address special environmental needs; for example, special resource waters, water quality control in cold climates, or merging NPDES stormwater permitting with total maximum daily loads (TMDLs).
- **Forms and maps**

At the Local Level:

Check with your local environmental management or public works department to see if your locality has obtained NPDES permit coverage, or whether it is in the process of obtaining coverage. Although state requirements vary, most MS4s are required to submit the following documents:

- **A Stormwater Management Plan (SWMP) or Stormwater Pollution Prevention Plan (SWPP)**: For localities covered under Phase II, there are six minimum control measures. The SWMP should include strategies and BMPs for those measures:
  - Outreach
  - Education
  - Construction
  - Post-Construction
  - Illicit Discharges Elimination
  - Pollution Prevention

  Under the new rules, MS4s need to include measurable goals, and show how the SWMP relates to water quality goals. The minimum measures listed above were not part of the original permit structure for Phase I permits, though the general tasks were required. In reissuing stormwater permits, many permitting authorities are modifying the permits to more closely dovetail Phase I and Phase II requirements to make it easier for these communities to work together.
- **Stormwater Ordinances**: Most states require that MS4s develop ordinances or other regulatory mechanisms to implement stormwater management controls. As you read draft language for ordinances, be prepared to compare the proposed legal language with language in your local smart growth codes and alert stormwater managers to inconsistencies.
- **Schedules for public meetings, regulation development, milestones and training.**

For more detailed information on water regulations and the Clean Water Act, see the River Network's "Understanding the Clean Water Act" at <www.cleanwateract.org>.

Connecting Stormwater Management and Smart Growth

Not so long ago, the predominant philosophy of stormwater control focused on flood control and directing water off an individual piece of property as quickly as possible. As towns grew, curbs, gutters, trenches, and pipes assisted the land use and stormwater planner alike in meeting this goal. While this turned out to be a successful strategy for individual properties, the additive effects of runoff from these individual properties on a watershed scale contributed to flooding and water quality problems. This has led water quality professionals to rethink stormwater control.

As a result, water professionals began to look at development site plans for opportunities to lessen the volume of stormwater generated from individual development projects. Better site design practices, such as low impact development, emerged as mechanisms to retain a site's natural hydrology and infiltrate stormwater within the boundaries of the development project. The conservation development movement was established—in particular, for new residential subdivisions.

These new subdivisions sparked debate over the overall environmental attributes of conservation development projects, however. Observers noted that, while these developments offer water-handling benefits on site, they can contribute to wider land disturbance activities, transportation impacts, and other quality problems related to the growth that follows housing subdivisions. At the same time, urban developers increasingly encountered resistance to infill and redevelopment projects based on predictions of additional stormwater-related impacts to urban streams. These discussions revealed the need for a more comprehensive view of the water quality impacts related to development, one that also considers a broader watershed context.

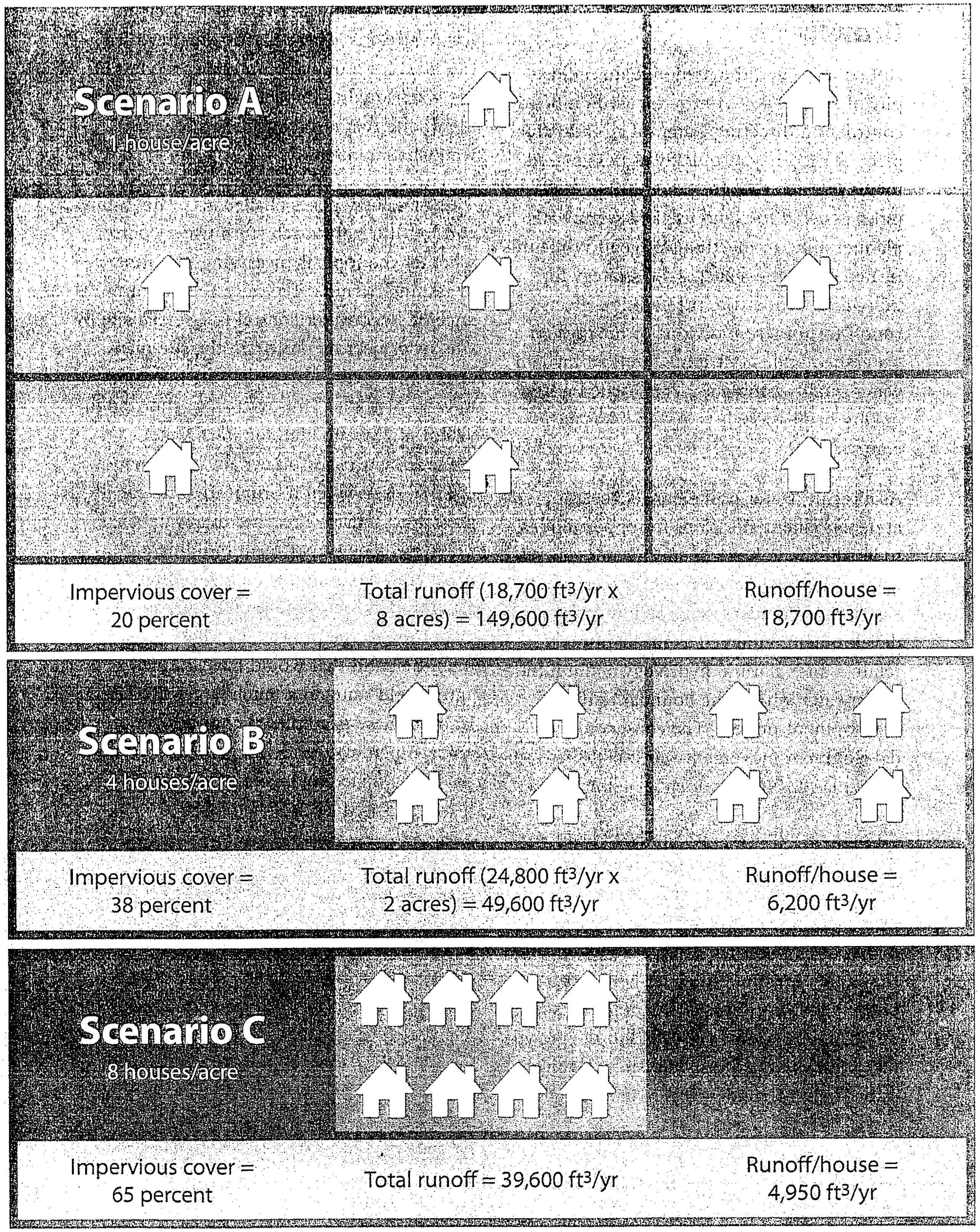
This new view poses challenges to how states and localities approach stormwater control, whether the topic is measuring performance or issuing permits. Typically, the performance of stormwater control is assessed site by site, or project by project in the site plan approval process for subdivisions or commercial districts. Thus, a conservation subdivision might rate high for stormwater management based on certain performance criteria, even when it brings unanticipated growth to sensitive reaches of a watershed. Likewise, a new apartment building and retail complex might get a low rating for creating impervious surface on an urban lot, even though the project absorbed development demand that would have gone to a "greenfield" site on a much larger footprint. In both these examples, a complex set of environmental considerations relate to the project's impact at the site, in the neighborhood, and at the watershed level.

Photo: EPA

This supermarket in West Palm Beach Florida was part of a downtown redevelopment project. The store, which brings everyday uses closer to in-town residential areas, is a smaller format and is accessible by several modes of transportation.

How Does Density Relate to Runoff? The Site Level

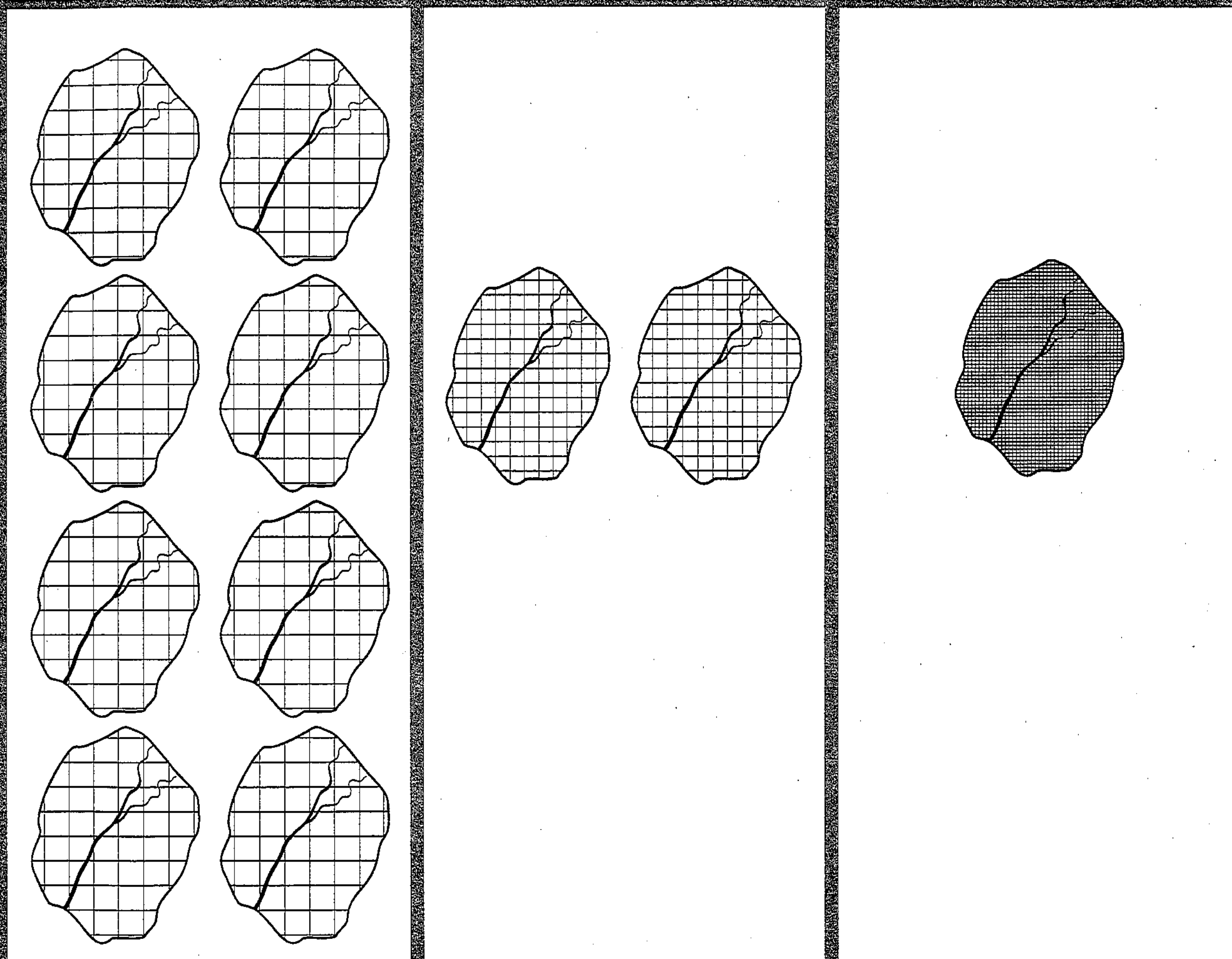
These three scenarios show how different housing densities on one acre can affect not only total runoff, but also runoff per hous Although the higher-density scenarios generate more stormwater per acre, they generate less total stormwater runoff and less stormwater runoff per house. Since most watershed growth is expected to be in the range of several thousand houses, not four or eight, the estimation of runoff based on per unit of housing is important. In addition, this illustration looks only at the lot and impervious cover related to the house footprint and driveway.



How Does Density Relate to Runoff? The Watershed Level

Housing density also affects the number of acres required to accommodate growth. At the site level, most regional and watershed managers are facing household growth estimates of several thousand units. By limiting housing production to one unit/acre, growth pressures do not cease, but rather growth goes elsewhere in the watershed, or expands to additional watersheds. Here, the higher-density scenarios consume fewer watersheds to accommodate the same number of houses. A fuller discussion of density and build-out is presented in EPA's 2005 document *Protecting Water Resources with Higher-Density Development.*

Scenario A | **Scenario B** | **Scenario C**



Scenario A

At one house per acre, 80,000 houses require 80,000 acres, or *8 watersheds*, translating to:

80,000 acres x 1 house x 18,700 ft^3 /yr of runoff

1.496 billion ft^3 /yr of stormwater runoff

8 watersheds at 20 percent impervious cover

Scenario B

At four houses per acre, 80,000 houses require 20,000 acres, or *2 watersheds*, translating to:

20,000 acres x 4 houses x 6,200 ft^3 /yr of runoff

496 million ft^3 /yr of stormwater runoff

2 watersheds at 38 percent impervious cover

Scenario C

At eight houses per acre, 80,000 houses require 10,000 acres, or *1 watershed*, translating to:

10,000 acres x 8 houses x 4,950 ft^3 /yr of runoff

396 million ft^3 /yr of stormwater runoff

1 watershed at 65 percent impervious cover

Many states and communities are using smart growth planning as a way to deal with the complex analysis for future growth and development. Smart growth is best described as a set of 10 principles, presented in Table 1.

While better stormwater management is not explicit in the 10 principles of smart growth, the water quality benefits are, quite literally, built in. These benefits typically emerge from policies that integrate local and regional decisions on transportation, housing, natural resources, and jobs. The interrelated benefits of smart growth are highlighted throughout this document and include:

- **Compact Project and Community Design:** One of the more powerful strategies for reducing the footprint of development, and hence the stormwater impacts, is to focus on compact development. For existing communities, policies to encourage infill and redevelopment can result in a smaller development footprint within the region. For new communities, compact designs that mix uses and cluster development help to accommodate development demand in a smaller area. Reducing the footprint of individual buildings can also be a strategy, though there are circumstances that call for greater lot coverage in districts where a higher development intensity is needed (for example, near transit stations). The compact form can also lend itself to more environmentally friendly transportation options, such as walking and biking.
- **Street Design and Transportation Options:** Well designed, compact communities are served by a highly connected street and trail system designed for multiple modes of transportation. The pattern need not be a grid, and in some areas, topography and environmentally sensitive areas will influence where roads go. Providing connections is the key to allow walking or bike trips, or to or to allow a "park once" trip for combining errands, recreation, and/or commuting. A compact district also provides for more efficient use (and reuse) of existing infrastructure.
- **Mix of Uses:** Another element that can contribute to decreasing the amount of stormwater generation lies in the development mix. By pulling a mix of jobs, housing, and commercial activities closer

Table1: Smart Growth Principles

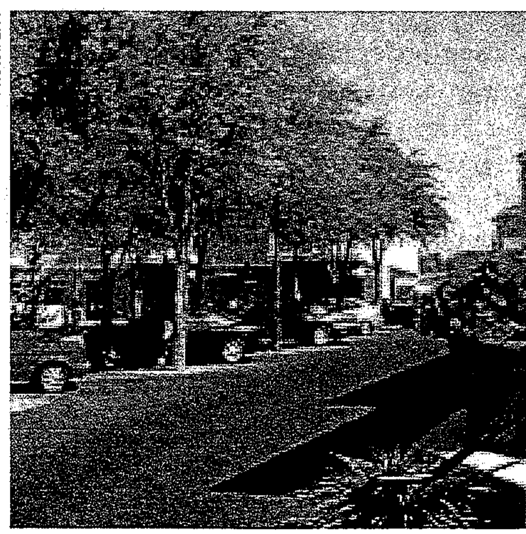
1. Create a range of housing opportunities and choices.
2. Create walkable neighborhoods.
3. Encourage community and stakeholder collaboration.
4. Foster distinctive, attractive places with a strong sense of place.
5. Make development decisions predictable, fair, and cost effective.
6. Mix land use.
7. Preserve open space, farmland, natural beauty, and critical environmental areas.
8. Provide a variety of transportation choices of smart growth.
9. Strengthen and direct development toward existing communities.
10. Take advantage of compact building design.

together, not only do you increase the transportation options for a community, but the requirements for transportation and infrastructure also change. The need to accommodate fewer auto trips supports a reduction in standard parking requirements. A mix of daytime and nighttime uses, or weekday and weekend uses, increases the chance that parking spaces can be shared among businesses.

- **Use of Already-Developed Land**: Most literature on conservation development is focused on clustered housing in greenfield residential projects; however, reuse of existing impervious surfaces can be regarded as a powerful form of conservation development. First, redevelopment conserves land by absorbing demand that could go into undeveloped parts of the watershed. Second, there is typically no net increase in runoff since impervious cover is essentially replaced by impervious cover. When low impact techniques and creative landscape design accompany a redevelopment project, the water quality performance at the watershed and site level is enhanced. Finally, there are less obvious factors associated with redevelopment that drive stormwater outcomes. In older parts of cities and towns, the development standards used for the original development were likely to have called for fewer parking spaces, a zoning mix, less roadway and less dispersed infrastructure. Thus, a new 10-unit building on the urban edge will likely have more related impervious surface than a 10-unit redevelopment project, even if the two have the same building footprint.

- **Better Models for New Development**: Where development continues to take place in undeveloped areas, smart growth designs can be used to improve the environmental aspects of that new growth compared to conventional, separated designs. While conservation design principles are important, smart growth development incorporates connections to jobs, schools, and other existing economic centers. A mix of housing types can alleviate the pressure to build affordable housing on more distant parcels of land. New town models such as Traditional Neighborhood Design or New Urbanist communities are advanced, in particular for transportation improvements. When combined with traditional water quality BMPs, the connected, compact, and efficient neighborhood designs can amplify the water quality benefits.

Photo: EPA



This mixed use center in Gainesville, Florida is served by a parking lot constructed of pavers, which helps support the street trees. The trees also provide shade for outdoor seating nearby.

Smart Growth Techniques as Best Management Practices

What do states and localities need to do to qualify smart growth policies as stormwater BMPs under stormwater permitting programs? Permitting authorities around the country are already introducing smart growth concepts into their guidance documents and permits. Some of the general concepts include:

- Coupling smart growth planning with site design criteria to further improve the watershed-wide benefits of the growth and redevelopment plans.
- Implementing watershed-wide or regional policies to consider simultaneously areas for growth and those for conservation.
- Better designs for reducing the impervious surfaces associated with development, such as compact street designs and lower parking requirements.

Notable examples include the following:

New Jersey has developed a successful strategy for considering both smart growth and stormwater in its state water quality and growth plans. In seeking to meet the dual goals of reducing runoff and replenishing aquifers, the state has developed policies to encourage growth in targeted areas while protecting environmentally sensitive areas and open space. The state's regulations are divided into requirements for runoff control and requirements for infiltration. Redevelopment and infill in designated urban areas are exempt from the stormwater infiltration rules. The reasons supporting the policy are: (1) recharge regulations can pose a regulatory barrier to redevelopment, (2) the regulations can be impractical in highly urbanized areas and (3) recharge is not always desirable in areas with environmentally compromised soils.

Supplying workforce housing closer to job and activity centers often helps relieve development pressure to build more affordable housing further out.

Photo: EPA

In **California**, the Santa Clara Valley Urban Runoff Pollution Prevention Program's (SCVURPPP's) 2001 Phase I permit renewal recognized that there could be cost-effective opportunities to implement stormwater control during the land use approval process. In particular, SCVURPPP noted several smart growth options, including neo-traditional street design standards and more effective use of existing parking spaces. The permit goes further, noting that certain development projects, such as transit villages, are likely to be exempt from several requirements because they are typically built in areas already covered with impervious surfaces.[3]

The SCVURPPP permit lists numerous criteria for onsite stormwater control requirements, but also include flexibility by allowing its permitees to document where standard criteria would be impractical, where compensatory mitigation would be allowed, and where localities could use alternative strategies to better match stormwater control techniques to the local condition.

San Jose, California, is one of the co-permitees under the SCVURPPP program. The city sought to incorporate the new guidance from the 2001 permit into its local stormwater ordinance and into its smart growth initiative, the San Jose 2020 Plan.

The two main areas that allow consideration of smart growth include:

- **Finding of Impracticality**: San Jose structured its policy to take advantage of the SCVURPPP permit's flexibility, as noted above. Under the permit, deviations from the standard requirements could be established through a finding of impracticality. San Jose's policy includes some of the more common reasons for a finding of impracticality, such as soil type, but also recognized that the natural onsite measures for infiltration and runoff control can be impractical in built-out, urban areas.
- **Flexibility**: If there is a finding of impracticality, the San Jose policy allows several alternatives to the permit's standards that recognize the water benefits of smart growth projects. The city established a category of smart growth projects that exhibit water benefits by virtue of the development of the site itself, the nature of the site design, and its location in the watershed.

Smart growth projects are defined by the city to be:

a. Significant redevelopment within the urban core;

b. Low-income, moderate income, or senior housing development project, meeting one of the criteria listed in other sections of the city's code; and/or

c. Brownfields projects.

While affordable housing may seem like an unconventional BMP, the city recognized the demand for low-income and senior housing would not go away, but likely relocate in remote regions where jobs and services were not as likely to be close at hand. Incentivizing construction through redevelopment thus became not only a housing strategy, but a watershed one as well.

Another California city, **Poway**, has defined BMPs to include redevelopment and development projects that improve stormwater performance as compared to conventional designs. The ordinance reads:

> *"Site design BMP" means any project design feature that reduces the creation or severity of potential pollutant sources or reduces the alteration of the project site's natural flow regime. Redevelopment projects that are undertaken to remove pollutant sources (such as existing surface parking lots and other impervious surfaces) or to reduce the need for new roads and other impervious surfaces (as compared to conventional or low-density new development) by incorporating higher densities and/or mixed land uses into the project design, are also considered site design BMPs.*

(Ord. 569 § 2, 2002) See <www.codepublishing.com/ca/poway/Poway16/Poway16101.html#16.101.200>.

In **Texas**, the North Central Texas Council of Governments (NCTCOG) is helping its local MS4s by identifying useful techniques for stormwater control. NCTCOG's guidance also directs readers to the various local regulations or ordinances that control how and

North Central Texas Council of Governments Guidance

Minimize Impervious Surfaces

Impervious surfaces are roads, parking lots, driveways, and rooftops that do not allow infiltration of stormwater into the ground. The increase in stormwater runoff, along with the pollutants the runoff picks up from impervious surfaces, cause major problems for our waterways. Narrower streets and smaller parking lots benefit the environment and can make a development more attractive as well.

- Develop residential street standards for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency vehicle access. *Street Specifications, Subdivision Ordinance*
- Consider limiting on-street parking to one side of the street. *Street Specifications, Subdivision Ordinance*
- Incorporate sunken landscaped islands in the middle of cul-de-sac turnarounds. *Street Specifications, Drainage Manual*
- Minimize street length by concentrating development in the least sensitive areas of site. *Zoning Ordinance*
- Reduce parking lot size by lowering the number of parking spaces (minimum and maximum ratios) and by sharing parking among adjacent businesses. *Zoning Ordinance, Development/Engineering Standards*
- Reduce parking requirements for developments in proximity to public transportation. *Zoning Ordinance*
- Provide incentives or opportunities for structured parking rather than surface parking. *Zoning Ordinance*
- Use pavers or porous pavement in parking overflow areas. *Development/Engineering Standards*
- Reduce frontage requirements in residential areas to reduce road length. *Zoning Ordinance*
- Reduce the rooftop area of buildings by constructing multiple level structures where feasible. *Zoning Ordinance*[4]

where impervious surfaces, such as parking lots or driveways, are located. (See box.)

The NCTCOG examples show that many of the most promising techniques for effectively managing runoff are often included in existing regulations and guidance traditionally associated with land development and transportation regulations, not stormwater control. In addition, the examples show that flexibility is needed, since not all regulations work equally well in all contexts. The North Carolina Smart Growth Alliance has pointed this out as well. In comments to the North Carolina Division of Water Quality on proposed stormwater rules, the Alliance notes that language in the state's 2003 proposal to establish impervious surface limitations on a site-by-site basis would have the effect of making sprawl-type developments easier to build, while making it more difficult to develop compact, walkable communities.[5] Blanket regulations that appear to make sense at the individual lot level can often have the unintended outcome of promoting development in areas of watersheds unable to handle new growth.

So, how do stormwater managers and their planning counterparts choose strategies and BMPs that serve the interrelated goals of watershed protection and successful growth and development? Matching the BMP (or

Table 2: Best Management Practices and Development Context

BMP Strategies	Urban/High Density Settings	Suburban/ Urbanizing Areas	Rural and Conservation Areas
Strategies for individual buildings and building sites	Bio-infiltration cells, rooftop rain capture and storage, green roofs, downspout disconnection in older residential neighborhoods, programs to reduce lawn compaction, stormwater inlet improvements	Disconnecting downspouts, green roofs, programs to reduce lawn compaction, bio-infiltration cells, rooftop rain capture and storage	Green roofs, housing and site designs that minimize soil disruption
Low impact development (LID) or better site design strategies	Ultra-urban LID strategies: high-performing landscape areas, retrofitting urban parks for stormwater management, micro-dentention areas, urban forestry and tree canopy, green retrofits for streets	Swales, infiltration trenches, micro-detention for infill projects, some conservation design, retrofitting of parking lots for stormwater control or infill, tree canopy, green retrofits for streets. Depending on location, larger scale infiltration.	Large scale LID: forest protection, source water protection, water protection overlay zoning, conservation, aquifer protection, stormwater wetlands
Infrastructure	Better use of gray infrastructure: repair and expansion of existing pipes, installation of stormwater treatment, fix it first policies, improve street and facilities maintenance	Priority funding areas to direct development, better street design, infrastructure planning to incentivize smart growth development, improve street and facilities maintenance	Smart growth planning for rural communities using onsite systems
Structural BMPs	Commercially available stormwater control devices, urban drainage basins, repair of traditional gray infrastructure	Rain barrels, bio-infiltration techniques, constructed wetlands	
Design strategies	Transit districts, parking reduction, infill, improved use of curbside parking and rights of way, brownfields, urban stream cleanup and buffers, receiving areas for transfer of development rights	Infill, greyfields redevelopment, parking reduction, policies to foster a connected street system, open space and conservation design and rural planning, some impervious surface restrictions, stream restoration and buffers, targeted receiving areas for transfer of development, planned unit developments	Regional planning, use of antidegradation provision of Clean Water Act, sending areas for transfer of development, watershed wide impervious surface limits, water protection overlay zoning districts
Watershed-wide or regional strategies	Transfer of development rights, waterfront restoration, participation in regional stormwater management planning/infrastructure	Regional park and open space planning, linking new transit investments to regional system, participation in regional stormwater management planning/infrastructure	Regional planning, use of antidegradation provision of Clean Water Act, sending areas for transfer of development, watershed wide impervious surface limits, water protection overlay zoning districts, water supply planning and land acquisition

combination of BMPs) to the development context is important. Some BMPs, such as green roofs, will work in almost any setting. Infiltration requirements pose challenges in urban areas, however, where legacy pollutants remain and/or where land costs are high. They also pose challenges in the development of new town centers or other compact districts that are constructed in greenfields.

Table 2 illustrates a breakdown of BMPs with respect to setting. It is not intended to serve as a fixed menu, but rather to provide a framework for refining the match of conventional stormwater BMPs to the development context. In fact, some of the measures that seem most fitting in suburban and rural areas, like stormwater wetlands, often have a role in ultra-urban settings. The Elizabeth River Project in Virginia is working with stakeholders to bring constructed wetlands and riparian buffers to urban areas and military facilities in the Portsmith/Norfolk area of the Chesapeake Bay.

Finally, and most importantly, BMPs are rarely used in isolation, but rather are strategically combined to achieve water quality goals and address target pollutants of concern. For example, a city may install a first line of BMPs to filter large debris, while a series of infiltration and filtering techniques are used to allow sediment to settle, improve infiltration, and reduce runoff. For smart growth techniques as BMPs, there are also strategic combinations of policies that serve to increase the environmental performance of development projects. For example, a plan for transit-oriented development may require that the mix of uses and density be coupled with better parking strategies so that walking and automobile travel are equally attractive. The ability to develop effective combinations of BMPs is among the most important features in developing joint stormwater and smart growth plans.

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1 U.S. Environmental Protection Agency. 1994. EPA-841-F-94-005. http://www.epa.gov/owow/nps/qa.html

2 Kosco, John, Wes Gunter, and James Collins. Lessons learned from in-field evaluations of Phase I Municipal Stormwater Programs. Presentation prepared for the 2003 National Conference on Urban Stormwater. Chicago, Illinois, February 17-20, 2003. www.epa.gov/owow/nps/natlstormwater03/19Kosco.pdf

3 http://www.scvurppp-w2k.com/pdfs/other/NPDES_Permit_C3New_Finalodrtransltr.PDF

4 Stormwater Management in North Central Texas. Post-construction runoff control, EPA recommendations. www.dfwstormwater.com/Storm_Water_BMPs/post-construct.asp#rec

5 North Carolina Smart Growth Alliance. May 16, 2003. Comments to the Division of Water Quality, Re: Proposed NPDES Phase II Stormwater Rules. www.ncsmartgrowth.org/archive/stormwater%205%2016%2003.html

SECTION 2

Specific Smart Growth Techniques as Stormwater Best Management Practices

The purpose of this section is to present common smart growth techniques, their water quality attributes and how to present them within local, state, or federal stormwater requirements. The NPDES stormwater requirements—in particular the Post-Construction Minimum Measure—have focused attention on how development projects, both individually and collectively, impact a watershed after projects are built. This section is geared toward the post-construction measure under Phase II, though any city or county renewing a permit under Phase I can use them. Additionally, cities, counties, and townships that are not regulated, but that are proactively developing stormwater, flooding, or watershed plans, can use the information to meet water quality goals.

The following list contains smart growth techniques that have been adopted by state, regional, and local governments for a variety of benefits, including environmental quality. This section will look at each of these techniques in depth, though this list is not exhaustive.

1. Regional planning
2. Infill development
3. Redevelopment policies
4. Special development districts (e.g., transit oriented development and brownfields redevelopment)
5. Tree and canopy programs
6. Parking policies to reduce the number of spaces needed or the footprint of the lot
7. "Fix It First" policies
8. Smart growth street designs
9. Stormwater utilities

Each subsection provides information and examples that:

- Define the smart growth technique.
- Give an overview of who to talk to about the techniques and relating it to stormwater.
- Define the stormwater benefits and provide tips on how to list the technique in your plan.
- Provide, if available, estimates of the costs associated with the technique.
- Provide examples where the technique has been adopted, or is in the development stage.
- Provide suggestions on "Measurable Goals," a requirement for all BMPs.
- Give "points to consider" in adopting the technique as a stormwater management strategy.

Outreach, Public Education, and Public Participation

Most smart growth initiatives include outreach to stakeholders, processes to integrate comments on plans, and schedules for gathering input. Stormwater managers should reach out to their counterparts in planning, zoning, transportation, and growth management departments to see where their established processes can integrate successful stormwater management. Ask the planning department or city/county manager if the following types of meetings are planned and whether they are open to a module or segment on growth and stormwater:

- Planning charrettes
- Visioning exercises
- Planning sessions on alternative growth scenarios
- Smart growth training sessions
- Transportation alternatives meetings with the public
- Watershed meetings

1. Regional Planning

Definition

Regional planning is the process of considering community development options across a particular area that can include several political jurisdictions. For the purposes of stormwater quantity and quality, a watershed can be thought of as a region. If smart growth is a cornerstone of your stormwater planning efforts, regional planning is critical. A watershed or regional effort can facilitate discussions that reduce impacts by directing growth while preserving critical areas. EPA encourages watershed planning as a way to comprehensively prevent and control water quality and quantity impairments.

Local governments are encountering a complex, and growing, array of requirements to meet various state and federal rules, as well as growing public demand for "quality of life" benefits such as open space, transportation options, and amenities at the neighborhood level. The planning requirements can include transportation at a regional level, growth management plans, source water protection plans, economic development planning, emergency response and evacuation plans, and updated floodplain mapping. Many elements of the various planning exercises are similar and rely on the same data sets, such as population projections and GIS mapping of natural resources.

For water quality, regional cooperation and planning is crucial for aligning smart growth and water quality approaches such as:

- Minimizing imperviousness at the watershed level by targeting and redirecting development
- Identifying and preserving critical ecological areas and contiguous open space areas
- Making maximum use of existing infrastructure and previously developed sites

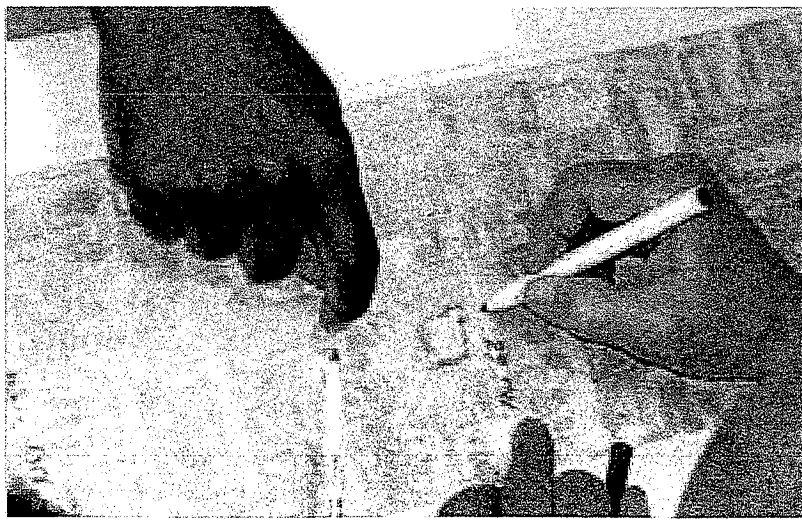

Photo: Local Government Commission

Effective stakeholder participation is a cornerstone of both stormwater and regional planning.

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Regional Visioning and Scenario Planning

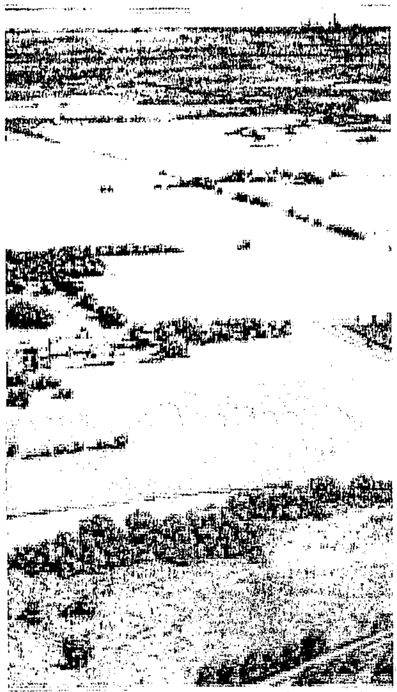


Illustration 1
Kane County/Gilberts Present Day

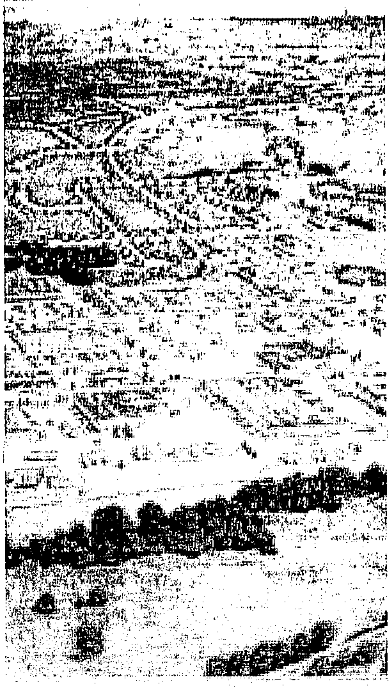


Illustration 2
Kane County/Gilberts Build Out Under Conventional Planning and Development

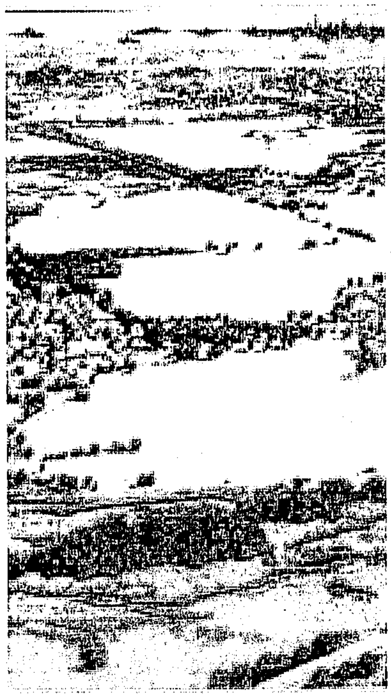


Illustration 3
Kane County/Gilberts Build Out Under Smart Growth Planning and Development

Plans by Dodson Associates, Ltd.; Illustrations by Jack Werner

This series of illustrations was developed for the Chicago Regional Environmental Planning Project to show development alternatives at the western edge of the Chicago suburbs in Kane County. This agricultural area is characterized by poorly drained soils and the presence of the Fox River, which was once viewed as a natural boundary for growth. Illustration 1 shows the emergence of some housing in the background.

Kane County expects growth to emerge with the further expansion of housing, roadways and their use. Office and research are the prime industries that are expected to expand into the area first. Housing and retail are expected to follow. Illustration 2 shows that current planning trends would dictate separated land uses, large set-backs, and individual parking lots. The stormwater runoff from the large parcels and parking lots would eventually impact the streambed illustrated in the foreground.

Illustration 3 shows an alternative future using smart growth practices. The industrial uses are placed in the background closer to existing infrastructure and development. Housing developments are connected to services and retail. Illustration 3 envisions a county plan where certain areas are preserved for agriculture and drainage while accommodating growth in village centers. For more information, see the Environmental Law and Policy's "Visions" report at <www.elpc.org/trans/visions/visions.htm>.

Who Do I Talk to About Regional Plans?

If your state has developed smart growth planning requirements, contact the state department of planning or community affairs. The Metropolitan Planning Organization (MPO) has the responsibility to develop master transportation plans. Subsection 8 (Smart Growth Street Designs, page 75) goes into more detail about planning for roads and transportation infrastructure. Your local Council of Governments (sometimes referred to as a COG) might also have information on planning efforts that span several jurisdictions. Although these may not be water plans per se, the population forecasting, maps showing undevelopable parcels, and vacant properties can all be helpful in developing a comprehensive stormwater management plan.

If your community is under the Phase II rules, and you are located near larger cities and/or counties covered by Phase I, determine if you can team up with them in developing plans. Since these communities are more than 10 years into planning and implementation, do not hesitate to contact the stormwater managers or public works department to see where you can share or expand upon plans and programs. Your area may also have other regional agreements that can be used to initiate stormwater plans, such as agreements on infrastructure or flooding prevention.

The Coastal Zone Management Act of 1972 (CZMA) and subsequent amendments have established a program for states and territories to voluntarily develop comprehensive programs to protect and manage coastal resources (including the Great Lakes). To receive federal approval and implementation funding, recipients are required to demonstrate that they have programs, including enforceable policies, that are sufficiently comprehensive and specific to regulate and resolve conflicts among land uses, water uses, and coastal development. There are currently 29 federally approved state and territorial programs. These plans may have elements and funding in place, and may include smart growth practices that can help develop elements of a stormwater management plan. For a link to state programs go to <http://coastalmanagement.noaa.gov/czm/>.

EPA's Office of Wetlands, Oceans, and Watersheds hosts a Web site called "Surf Your Watershed." This site allows users to enter their zip code, local stream name, or locality to find information about their watershed, as well as planning efforts and relevant watershed organizations. Visit <www.epa.gov/surf>.

Stormwater Benefits

Regional efforts to encourage development in strategic areas are one of the strongest approaches to coordinating growth and resource protection in a watershed. Regional efforts are often needed to effectively coordinate local approaches to development and achieve better watershed-wide results. Communities should determine areas where they want growth to occur and areas they want to preserve. When such areas are clearly defined and articulated within a region,

New Jersey Highlands: Regional Planning for Water and Growth

The 800,000+-acre New Jersey Highlands Region covers more than 1,250 square miles and 88 municipalities in seven counties (Bergen, Hunterdon, Morris, Passaic, Somerset, Sussex and Warren). The Highlands Region is an essential source of drinking water for half of the residents of New Jersey. In 2004, the Highlands Water Preservation and Planning Act (The Act) was adopted to balance the management of water resources and growth.

The Highlands Act documents the geographical boundary of the Highlands region and establishes both the Highlands preservation area and the Highlands planning area. The Highlands Act requires the New Jersey Department of Environmental Protection to establish regulations to limit land disturbance in preservation areas, while creating a regional master plan to direct growth to desired areas within the region. To carry out the Act, the Highlands Water Protection and Planning Council was formed and charged with preparing the regional master by June 2006. While the focus of the regional plan is seen as land preservation for water quality and supply, the council was also charged with including elements to encourage appropriate development, redevelopment and economic growth for areas so designated.

In the Planning Area, municipal compliance with the Plan is voluntary. The Act provides incentives for conformance to the Regional Master Plan, however. The incentives include planning grants to assist in preparing local master plans and land use ordinances, technical assistance, tax stabilization funding for funding decreases accorded by participating in the plan, enforcement of the regional Master Plan and legal assistance to meet challenges to new master plans and zoning.

The council established several categories for grants, including grants to participate in Municipal Partnership Pilot Programs, Zoning and Parcel Analysis, Wastewater Capacity Analysis, and Affordable Housing. In 2005, Washington Borough was awarded a Municipal Partnership Pilot Program grant, which will be used to plan for three distinct areas: town center redevelopment, historic preservation, and stream corridor preservation (to include stormwater management). For more information on the New Jersey Highlands Council, visit <www.highlands.state.nj.us/index.html>.

For more information on the state of New Jersey's innovative state planning, see New Jersey's Web site on the Highlands Act, <www.state.nj.us/dep/highlands/faq_info.htm>.

development is encouraged on land with less ecological value, such as previously developed areas (as described in subsequent chapters for redevelopment, brownfields, greyfields, and vacant properties). Land with higher ecological value, such as aquifer recharges areas, wetlands, marshes, and riparian corridors, is then preserved or otherwise set aside for ecological services.

A 2004 study conducted by researchers at Texas A&M University evaluated development in a watershed in the greater Houston Texas area. The study tracked development trends over a 50-year period to evaluate watershed performance—in particular, as it relates to flooding. The study evaluated common indicators of development (e.g., impervious cover) and how various land development scenarios during that time period might have altered water flows and flooding.

The study found that the impervious cover alone was an inadequate indicator, but when considered with other indicators, such as indicators of development dispersal, these measures together proved to be a better predictor of flooding. In assessing total developed area, the researchers looked not at estimates of impervious surface area per lot, but rather whether the lot had any development at all.

The researchers also evaluated off-site development features such as roads and highways. Over a 50 year period, the researchers mapped total developed areas, with special attention to roadway lengths, and the ratio of commercial and residential units. The risk of flooding increased exponentially once the percentage of developed properties in the watershed reached 25 percent. From a regional perspective, the authors suggest that the percentage of impervious surface cannot be used as an indicator independent of other factors such as the configuration of infrastructure, development form, and a total proportion of properties that have been developed.[6]

In evaluating the environmental performance of successful smart growth planning on a regional basis, some localities and states are using build-out and capacity analyses to predict the condition of water resources once developable parcels are developed. Build-out analyses can be conducted based on existing land use regulations, or according to conventional development practices that could shape future proposals. The goal is to compare a smart growth development plan or project to a conventional model under *status quo* zoning, and compare the stormwater benefits.

For example, many communities are updating floodplain maps. Suppose a review identifies 1,000 acres of sensitive land critical for water filtration, absorption, and flood prevention. As a result of the review, the local government alters scenarios in planning documents to upzone land in the floodplain for development. The city and county confer, and as a result, the two jurisdictions revise planning and zoning documents to redirect growth to an area of the watershed that is more appropriate for development. In this case, the stormwater benefits are not only environmental in nature, but also avert the costs associated with property damage from flooding. Thus, the benefits extend beyond typical environmental measures of water quality and quantity to economic factors as well.

Typical Costs

The costs of regional planning are related to administration and research, and vary significantly depending on the resources already available in your community. Before estimating the costs of developing or fine-tuning an existing plan, it is helpful to understand the elements of the plan, the data needed to develop the various plans, the shape of the final product, and details on how the plan will be implemented.

The costs associated with aligning multiple plans are typically driven by staff or consultant time. The Southeastern Watershed Forum estimates, as a rule of thumb, that analysis, review, and coordination takes two to three staff working over one year to 18 months.

Once your community has decided to hire a consultant, the next step involves developing a Request for Proposals (RFP) or a Request for Qualifications (RFQ). The University of Wisconsin has developed a concise guidance document on the process of hiring a consultant. One step in the process can be issuing an RFQ to get a manageable pool of the most qualified consultants. As you draft your RFP or RFQ, keep in mind some of the unique challenges that will arise in drafting a joint stormwater and smart growth planning process, a comprehensive plan, and an implementation course. For example, you might want to have consultants review the comprehensive plan and NPDES permit (or permit renewal) and ask where there are barriers and flexibility. In addition, aligning multiple plans might reveal conflicting land use, transportation, and resource protection scenarios. Ask consultants how they would resolve these issues—in particular, where several jurisdictions are involved. Finally, ask them what elements of your strategic or smart growth plan can be borrowed for water quality and stormwater planning. These additional steps might add to the scope of work and budget; however, reviews of existing plans might reveal that work needed for comprehensive stormwater planning has already been completed. See <http://cecommerce.uwex.edu/pdfs/G3751.pdf> for more information.

Measurable Goals

The NPDES municipal stormwater program requires Phase II MS4s to include measurable goals in their program for each BMP. Increasingly, cities covered under Phase I MS4 permits are beginning to include measurable goals to track their performance in meeting water quality goals. Participation in a regional planning effort can be one way to track measurable goals, as can specific activities and steps outlined in a regional planning process. Information on counting participation in a regional group for meeting the requirements of the six minimum measures is described in the rest of this subsection, as are examples of specific activities that can count in the post-construction minimum measure.

Adoption of a regional master plan or watershed plan, as well as supporting policies and ordinances, are good candidates by which to measure progress in managing stormwater. These activities can also be documented to meet requirements on public education and outreach on stormwater impacts, as well as public involvement/participation. The key is to make sure you can track progress and relate the success back to the water quality goals in your regional stormwater management plan. For example, if a parcel of land identified for a regional park system is also contained in your regional aquifer protection plan, coordinate the acquisition and park design to meet stormwater and recreation goals. Include the acquisition in your monitoring and BMP maintenance plans as well.

In addition, efforts to coalesce common items among plans can be included in a stormwater management plan (e.g., merging plans to repair streets and sidewalks to spur redevelopment on a regional transportation corridor can be coupled with installation of microdetention areas between the curb and sidewalk). This effort can also help align capital spending decisions and be included in meeting regional stormwater goals to direct development.

Arlington, Virginia's high-density approach around the Rosslyn and Court House subway stations directs a large amount of growth to a small footprint. The county allows for high densities around stations, with a formula that tapers development intensity down to existing neighborhoods. This area, which stretches three miles from the Potomac River to the Ballston station, will ultimately absorb 8 million square feet of development on 2 square miles of land. This smaller footprint not only has regional stormwater benefits, but also has resulted in higher transit use and traffic counts that are far less than originally projected.

Photo: Arlington County, Virginia

Many areas across the country have identified specific plots of land to acquire. Buying parcels that have water-handling characteristics can provide a region with specific, measurable targets within a stormwater management plan.

For post-construction measures, the build-out analyses mentioned previously can be used to establish a baseline for setting measurable goals. Most states or regions develop build-out scenarios to assess how much developable land is available, whether the existing or planned infrastructure is likely to meet the needs of a built-out region, and to develop alternative planning scenarios. Most build-out analyses look at sewage capacity, source water, and water supply. With slight modifications, the build-out analysis can be used to also assess impervious surface coverage within a watershed and areas with the potential to effectively handle growth. If your city or county (or a regional organization) is developing build-out analyses, see if you can add a stormwater component so that alternative scenarios chosen include stormwater runoff parameters as well. EPA hosts a Web site with information on build-out analyses and other tools at <www.epa.gov/greenkit/2tools.htm>.

For meeting the post-construction minimum control measure, regional organizations might be called upon to develop model ordinances or individual policies to carry out regional plans. For example, the transfer of development rights is a tool used across the country to direct development away from environmentally sensitive lands while shifting the development to areas targeted for growth. This type of program might require setting measurable goals in a series. For example, in the first four years, the measurable goals might include (1) a formal agreement among participating jurisdictions, (2) a final comprehensive plan for the receiving area (3) a completed legal framework to administer trades and (4) software to track the number of trades. Given the complexity of each component, there are likely to be detailed sub-goals spelled out as well. To have a long-term effect on stormwater, your community should be prepared to count the numbers of transfers, not just the existence of a program.

Many regional organizations rely on voluntary participation in regional planning. As such, regional growth and/or watershed plans offer incentives (see the box on page 30, New Jersey Highlands, for more information). In addition to taking advantage of the incentives, make sure to also count the steps taken for the regional plan into your Phase I or Phase II municipal NPDES permit.

Examples

Within New Jersey, the Regional Planning Partnership (RPP) has developed tools to compare smart growth versus conventional development impacts, including stormwater runoff. The partnership has developed a sketch tool called Goal Oriented Zoning. In 2003, RPP developed a comparison for Delaware River Basin communities. This analysis compared four scenarios and set an overall watershed impervious cover goal at 10 percent. From there, RPP developed different development scenarios based on the 10 percent coverage goal to compare watershed-wide impacts. The exercise also served to show graphically what build-out is allowed under current zoning. While the use of the tool was meant to focus on zoning and transportation issues, RPP was able to include several environmental indicators, which could be further explored with air and water quality-specific models on other scales. For more information, visit <www.planningpartners.org/services.html>.

The Association of New Jersey Environmental Commissions (ANJEC) has issued a series of reports to assist its member communities with tools needed to comply with New Jersey's planning laws. These reports include information on conducting build-out and capacity plans, increasing the supply of affordable housing and implementing master plans. Its "Smart Growth Survival Kits" contain information on the data needed, methods available, and additional contacts. Though New Jersey–specific, the information can be useful for other states. Visit <www.anjec.org> and click on "Smart Growth Survival Kit."

In 2005, the Southwestern Regional Planning Council, covering the southwest counties in the state of Connecticut, released its regional planning strategy. The goals of the regional plan focus on transportation, housing, and directing development to areas with existing infrastructure and investment. For more information on implementation and other related objectives, visit <www.swrpa.org/projects/regplan2005.htm#project_team>.

To assist the regulated municipalities in the Syracuse Urban Area in complying with Phase II stormwater regulations, the Central New York Regional Planning Board (CNY RPDB) has launched a unified, regional assistance program. Its Web site, which was developed specifically for decisionmakers, includes several layers of maps, including MS4 boundaries, watershed boundaries, and political boundaries. The CNY RPDB is also providing unified assistance in the areas of public education, outreach and participation, municipal training, research assistance, and efforts to secure funding for compliance. For more information, visit <www.cnyrpdb.org/stormwater-phase2/>.

The 1996 Amendments to the Safe Drinking Water Act resulted in a focus to protect drinking water sources to complement the original goal of removing contaminants from drinking water. To meet the new requirements, states must ensure that each water system has a Source Water Assessment. Once the assessments are complete, states and localities work on action plans to address any issues found in the assessment. Source Water Assessments must include four basic elements:

- A delineation (or mapping) of the source water assessment area.
- An inventory of actual and potential sources of contamination in the delineated area.
- An analysis of the susceptibility of the water supply to those contamination sources.
- A mechanism for sharing the results widely with the public.

While the traditional sources of contaminants arise from agriculture or industrial uses, more and more communities are concerned about the cumulative effects of development and runoff on source water.

If you are developing a regional or comprehensive plan, check to see if there is a source water protection plan or ordinance in your area. A link to state programs can be found at <www.epa.gov/safewater/source/contacts.html>. In addition, the Trust for Public Land has issued a report called *Protecting the Source*, which contains information on joint land and water planning. Visit <www.tpl.org/tier3_cd.cfm?content_item_id=1337&folder_id=195>.

Points to Consider

In many parts of the country, local government boundaries have served more to foster competition than cooperation. Growth pressures, economic conditions, and the underlying structure for assessing taxes all put pressure on the local funding base. In addition, there are few incentives to plan across boundaries, much less develop interlocal agreements involving tax sharing, growth, or annexation laws. Nonetheless, some areas faced with mounting water-related problems are finding that shared solutions among counties and cities offer efficient options. Newspaper headlines on flooding, beach closures, and emergency water restrictions are motivating discussions on how to analyze problems and forge solutions that transcend boundaries. EPA has recognized the importance of watersheds as an effective organizing unit. A good resource for approaching interlocal agreements is the Joint Center for Sustainable Communities. The center represents an important collaboration between the National Association of Counties (NACo) and the U.S. Conference of Mayors (USCM). Its web site is <www.naco.org>.

Onsite Wastewater Treatment Systems (also referred as septic systems, package plants, or cluster systems) pose challenges to local governments trying to manage growth in rural counties, vacation areas with second homes, or in fringe areas where water infrastructure cannot be extended. In the past, soil percolation rates, drainage fields, and overall perceptions of septic tanks were limiting factors to widespread use. New technologies, growing demand for housing in rural areas, and changing perceptions have reduced barriers to their use, however. According to EPA's 2002 *Onsite*

Wastewater Treatment Systems Manual, nearly one-third of new housing construction is served by onsite wastewater treatment systems.[7] The University of Rhode Island's Cooperative Extension Agency has released a new handbook entitled *A Creative Combination: Merging Alternative Wastewater Treatment with Smart Growth*. The aim of the handbook is to help local governments address growth and wastewater handling at the same time. In addition, the handbook addresses the important role of management, oversight, and enforcement in areas where a large percentage of households use onsite systems to treat wastewater. For more information, visit <www.uri.edu/ce/wq/mtp/PDFs/manuals/Creative%20Combination%203-10.pdf>.

As noted in this section, regional planning can result in decisions that direct growth to certain areas of the watershed. These identified growth centers might be in existing communities, or in undeveloped areas. Efficiently handling growth in these areas eventually leads to discussions on density. Commonly held views on density among stormwater engineers and environmental advocates tend to equate density with imperviousness, which is then equated with poor water quality outcomes. Stormwater ordinances that discourage "connected impervious surfaces" might run counter to smart growth plans that call for a compact, but connected, street development form. Even where localities understand the need to direct density, there may be discussions about requiring automatic "offsets" of open space tied to redevelopment decisions. While some communities will establish programs to connect infill development with land conservation, a blanket, inflexible requirement to obtain land might, in the end, stifle a region's ability to meet both growth and water goals. To address the issue, EPA has issued a report called *Protecting Water Resources with Higher-Density Development.* [8]

Comparing the environmental impacts of various development options can require an extensive amount of baseline data and resources to analyze the various build-out scenarios. The baseline data needed include an inventory of natural resource lands, an inventory of developable lands, an inventory of undevelopable land in both private and private hands, and comprehensive zoning maps. Even where these data are available and show opportunities for redevelopment and reuse of vacant properties, further work might be needed to determine which properties are market-ready and which are contaminated, or where ownership is uncertain. In some communities, incomplete data may be a huge constraint. In these situations, communities might want to canvass state, university, and conservation district offices to see where GIS work has been conducted.

A community that does not have all of the information listed above might want to begin work in a targeted area. For example, if your state is updating transportation plans, a city or county may want to update local zoning maps to support the redevelopment of parcels in proximity to the study area. Information from this type of review can be used to assess development potential, transportation impacts, and scenarios of how that same level of development might look if built elsewhere in an undeveloped portion of the watershed. A carrying capacity report can then evaluate the stormwater generated by each scenario. The targeted

Photo: www.pedbikeimages.org/Dan Burden

Main Street Programs have been successful in directing development to older downtowns.

review can reveal not only environmental information, but also economic barriers and transportation investments that need to be addressed before growth is redirected.

If you are a Phase II community and decide to team up with Phase I community, keep in mind that some of the requirements for Phase I can be more restrictive than Phase II. Some Phase I communities use numeric goals for BMPs or might have implemented rigorous water quality monitoring schedules. The additional requirements may be offset by the efficiencies of using an established program, however.

Finally, regional or watershed plans, like any other plan, are only meaningful if implemented. When identifying measurable goals, be sure to distinguish where development of a plan is a suitable short-term outcome and which actual policy changes are needed to ensure the long-term environmental outcomes desired.

2. Infill Development

Definition

For purposes of this document, infill is defined as development that occurs on previously undeveloped lots within existing developed areas (the following section on redevelopment covers development that occurs on previously developed lots). Infill development takes advantage of built-out areas that are already served by a variety of transportation modes and by infrastructure. Infill development also accommodates development that might otherwise occur on greenfields sites. EPA's model permit for Phase II <www.epa.gov/npdes/pubs/modpermit.pdf> states that communities can use policies that promote infill development and development in areas with existing infrastructure to meet the post-construction minimum control measure. This section describes how infill development is typically regulated, how infill is treated within smart growth plans, and special points to consider for infill and stormwater control. Much of the information presented here is also relevant for Subsections 3 (Redevelopment) and 4 (Development Districts) as well.

Who Do I Talk to About Infill Plans?

Decisions about where to develop are influenced by numerous factors. While the final decision nearly always is left to the local jurisdiction, regions and states also influence the decisions of both developers and the localities through incentives and policies. This subsection therefore addresses policies at all three levels of government.

Green roofs can help manage stormwater for infill development projects.

Photo: University of Connecticut Cooperative Extension System

Local Jurisdictions: To understand who to talk to and where to find the land use plans that guide infill development, it is helpful to understand the two ways that localities manage development activities. The most common method in urbanized and urbanizing areas is through zoning, which places limits on the use, type, size, and design of allowed development. Zoning can be either "by-right," meaning that developers can build any development provided it meets zoning standards, or conditional, meaning that developers must seek approval for specific proposals. Within zoning codes, there are standards, called "bulk regulations," that govern the maximum size of structures on a lot and how the building is located on the site (e.g., lot coverage, setbacks, parking, floor area ratio, and landscaping requirements). Localities often use a variance process where deviations from the standards are deemed acceptable.

A second method of steering development is through use of incentives. Local jurisdictions seeking specific types of development might give financial or other incentives to developers willing to build within desired parameters. Zoning and incentive programs are typically drafted by the planning and/or building departments of a city and codified in city land use and zoning ordinances. If you are in a smaller municipality without zoning, the city or county engineer might be the best person to explain development rules, since building standards—not zoning—guide where development can be located and how it is built. Some larger cities have separate entities to encourage redevelopment, so personnel in the economic development division are likely to have the best understanding of whether there are special business development zones, special tax zones, and maps showing the boundaries of these areas.

If you are unfamiliar with the terminology used for zoning and comprehensive planning, visit the Wisconsin Department of Natural Resources Web site, which posts a list of general land use terms to help natural resource professionals. See <http://dnr.wi.gov/org/es/science/landuse/education/GPZ.htm>.

Regions: Metropolitan planning organizations (MPOs) are inter-governmental institutions formed to handle transportation planning in areas with a population of 50,000 or more. They also have the responsibility of allocating transportation funding for areas with populations greater that 250,000. MPOs might seek to better match development and transportation investments through educational tools; for example, maps showing 20-year growth projections. Some MPOs are involved in water and stormwater planning. To find out if your area is served by an MPO, contact your planning staff, or go to <www.ampo.org>, which lists member MPOs.

States: A number of states have passed statewide smart growth legislation, recognizing that, while development decisions are made locally, state policies often guide the decisionmaking process through financial incentives and policy decisions. Responsibility for statewide smart growth policies generally lies in a statewide smart growth office or planning office, or in a department of consumer or environmental affairs. In states that do not have a formal statewide plan, there may be separate policies that seek to streamline policies on growth. States that have embarked on growth management efforts might also have developed baseline data on natural resource lands and larger infrastructure programs. Contact the state office to see if you can make use of the GIS mapping or other data for making decisions on directing growth and infill. If your state has passed legislation, enabling legislation or programs to promote infill as a smart growth policy, but your locality has not adopted them, you might want to work with your zoning or economic development director to take advantage of the program for water and growth goals.

Stormwater Benefits

Infill can reduce potential runoff by ensuring that growth does not create additional impervious surfaces on the developed fringe and in environmentally sensitive areas. The impacts of such development can be considerable. Growth on the undeveloped fringe results in less groundwater flow into streams and less aquifer recharge as water runs over the surface. The 20 regions with the greatest amounts of land development over the period 1982 to 1997 now lose between 300 billions and 690 billion gallons of water annually that would otherwise have been captured in groundwater supplies through natural percolation.[9]

Photo: www.pedbikeimages.org/Dan Burden

Infill development can help a community grow over time. For example, a row of "liner shops" can be added to surround a surface or structured parking lot. This adds development intensity, reduces the overall amount of parking required for the district as a whole, and improves the pedestrian environment.

A modeling study conducted by Purdue University estimated that placing a hypothetical low-density development at the Chicago fringe area would produce 10 times more runoff than a mixed-use development in the urban core.[10] In Virginia, a Chesapeake Bay Foundation study found that clustered development across the state would convert 75 percent less land, create 42 percent less impervious cover, and produce 41 percent less runoff.[11]

In addition, infill development can make use of existing infrastructure. Guiding development to existing areas also increases the economic activity and tax base needed to support the maintenance, repair, and/or expansion of the water infrastructure in place. This investment can help repair areas prone to sewer overflows, or enhance treatment facilities in order to meet more stringent water quality standards.

The following measures are the types of regulations and programs that are used to promote infill, and thus facilitate stormwater improvements. In your permit application or plan for Post-Construction Minimum Control Measures, you can list these out separately, or include them under a general measure such as "infill policies."

Setbacks: Setback requirements can be one of the most important factors shaping the built environment—and hence impervious cover—in your community. Conventional codes often call for minimum setbacks: for example, requiring a building to be *at least* 50 feet from the street or adjacent properties. Smart growth codes often use maximum setbacks, which stipulate a maximum distance a building may be situated from the street or sidewalk. A maximum setback brings the building closer to the street and sidewalk, promoting a more interesting and efficient pedestrian environment. Alternatively, your smart growth code may stipulate a "build to" line. This requires that the building footprint meet a certain line along or within the property, such as up to the edge of a sidewalk. Check with your zoning, planning, or public works office to see if your community has minimum setbacks, or if it has made modifications to allow for maximum setbacks. The convention of setting minimum distances from the roadway can result in excess impervious cover and be ripe for reform to obtain stormwater benefits. Setback requirements can be found under individual zoning codes or apply to entire districts.

Mixed Use Zoning: Mixed use zoning allows (or sometimes requires) buildings with different uses (e.g., residential, office, retail) in the same area or in the same building. This mix allows for a greater intensity of development on a more compact scale, which reduces the amount of land needed on a per unit basis. Mixing uses also supports a range of transportation options and facilitates shared parking, thereby reducing the amount of surface needed for roads and parking lots.

Smart Growth Lot Sizes: In some areas, zoning codes and subdivision standards have been rewritten to allow for greater density and more efficient use of the land. Instead of requiring a minimum of a quarter acre per residential lot, as many current codes do, new smart growth codes allow smaller lots. This practice consumes less land per unit. The smaller lot sizes can also be instrumental to drawing development to smaller or oddly shaped infill lots within an older city. Large lots not only consume more land, but the lawns covering those lots handle less stormwater than undisturbed land. Under typical subdivision construction practices, sod is laid over highly compacted soil, so that water does not percolate. Where mass grading is a typical practice, the compaction of the underlying soil further reduces the potential for infiltration. Lawns treated with fertilizers and chemicals further add to stormwater problems, particularly if treatment occurs right before a rain event. Smart growth can minimize some of these impacts. When looking for language governing lot sizes, the zoning code may refer to "maximum lot sizes," or be presented as zoning categories, such as R-8 (or eight residential units per acre).

Density Bonuses: Density bonuses are used to provide incentives for developers who agree to integrate desired features into development projects. There can be stormwater benefits to increasing the development density in existing communities (e.g., less land consumption, more efficient use of existing impervious surfaces such as roads and sidewalks). One can also provide density bonuses to developers who agree to treat stormwater on site or who agree to replace older infrastructure serving the project. A density bonus may be used to reduce the footprint of the building by allowing the development intensity to be expressed through height. Density bonuses are typically part of a larger planning process that determines how much incentive is needed, what the amount of the bonus will be, enforcement to ensure both parties adhere to the arrangement, and other planning needs that accompany the added density (e.g. parking, fire protection). Density bonuses are typically listed in the zoning code or plans, or in footnotes to the plan.

Financial Incentives: Common incentives include the use of tax-increment financing, tax and economic incentives for redevelopment, and promotion of cost-of-service utility fees (instead of average cost pricing, which can subsidize dispersed development at a cost to higher density development). Tax increment financing (TIF) is a system whereby property taxes in a particular district are frozen at a certain level; when property values rise, the additional tax that would have been paid is instead directed back into redevelopment projects in the district. TIFs are built on the concept that new value will be created, and that the future value can be used to finance the initial investment.

Typical Costs

Both conventional development and infill involve costs to the public sector, because any new development requires public services or upgrades. Most research, however, finds that in the long run, there are fewer public costs to provide services to infill and redevelopment, because existing infrastructure is used or repairs or upgrades were needed whether infill took place or not.[12]

Measurable Goals

An initial goal might be to direct some percentage of growth into areas that are already developed, or to initiate a selected number of policies to encourage infill development. To ensure measurability, your community can establish a system to track building permits within an area designated for infill. In addition, your community can institute a priority system for infill and redevelopment projects that further improves stormwater management with features such as green building techniques. A longer-term goal might be to increase the overall density of developed areas and preserve open spaces from development. A locality may want to do a "code checkup" every so often to make sure that

Photo: EPA

Landscaping can be used to handle stormwater in tight infill projects. While native plants are often recommended, there may be other factors to include in plant selection, such as maintenance, canopy, root depth, and water uptake.

the requirements for infill are not more onerous than those established for new development on greenfields sites.

Examples

The state of **Washington** has developed a Phase II application that explicitly lists infill development as an option for fulfilling the post-construction minimum control measure. To view the Department of Ecology's permit application, go to: <www.ecy.wa.gov/programs/wq/stormwater/phase_2/Phase%20II%20Application.pdf> (see page 14 within the document for the language on infill development).

Clark County, Washington, adopted an infill ordinance in fall 2002. Its infill guidelines are applicable only in certain residential zoning districts for lots under 2.5 acres that adjoin existing development and can be served by existing infrastructure. The ordinance allows for two tiers of infill development. Tier 1 allows only detached single-family housing, but lot sizes can be smaller than existing zoning. Tier 2 allows attached and detached single-family housing, as well as duplexes and multi-family housing. Developers may also receive density bonuses. Infill projects are exempt from stormwater regulations if they create less than 5,000 square feet of new impervious surface. For more information on the infill ordinance and Clark County's comprehensive plan, visit <www.co.clark.wa.us/longrangeplan/review/index.html>.

In its state model stormwater ordinance, **New Jersey** has identified areas slated for redevelopment and infill. Rather than devote resources to establishing new boundaries for water policy documents, the state used definitions that already exist for economic planning. Thus, parcels in areas designated as "Urban Redevelopment Zones," such as "Urban Enterprise Zones" and "Urban Coordination Council Empowerment Neighborhoods," are exempt from infiltration requirements. By using the existing designations, the office overseeing stormwater efforts need not devote resources to drawing new boundaries. In addition, the use of economic development boundaries helps to tie environmental protection to economic development efforts. For more information, see <www.njstormwater.org> and go to the Tier A model permit.

Austin, Texas, has established a variety of water policies for its Desired Development Zones (DDZs) and Water Protection Zones (DWPZs). In the past, the city provided reimbursement for certain water and wastewater facilities over a three-year period. Under updated smart growth policies, major water and wastewater facilities located in the DDZ will be reimbursed in a single payment. Within the DWPZ, reimbursement for wastewater facilities will be discontinued, and the reimbursement schedule for water facilities will increase from three years to four. For more information on Austin's smart growth incentives page, see <www.ci.austin.tx.us/smartgrowth/incentives.htm>.

Some states have adopted priority funding areas (PFAs), which are areas designated for growth and, as such, gain priority for grants, infrastructure, and transportation investments. In creating these zones, the states typically inventory how funding is allocated, and create (or adjust) the funding formulas

Incorporating Infill into Stormwater Regulations: Wisconsin Department of Natural Resources

The Wisconsin Department of Natural Resources has developed technical materials and guidance for the post-construction minimum measure under Phase II, which address new development, redevelopment, and infill separately.

Definitions

The definitions help establish the development and regulatory context.

- "New development" occurs on undeveloped area including cropland and other vegetated areas.
- "Redevelopment" describes an area where impervious surfaces (e.g., buildings, parking lots, and roads) already exist.
- "Infill area" describes undeveloped land in existing sewer service areas that is surrounded by developed land or man-made features where development cannot occur.

The Post-Construction Rules

The rules focus on three aspects of stormwater-related impacts: 1) total suspended solids (TSS), 2) infiltration, and 3) peak runoff rates.

TSS refers to a measure of the amount of solids in the wastewater—in this case stormwater. TSS is a way to determine water "cloudiness," which has implications for the biological functions of aquatic species. To assess TSS, water samples are passed through a filter, and the amount of material captured is measured relative to the amount of water filtered.

Wisconsin's requirements for the percent reduction of TSS are measured from a "typical development pattern with no controls" or "no BMP" baseline and are tiered as follows. For new development, an 80 percent reduction from "no control." For redevelopment, a 40 percent reduction from "no control."

For infill, the requirements are:

- Less than 5 acres and developed prior to October 2014, a 40 percent reduction from "no control"
- Otherwise an 80 percent reduction from "no control"
- The 5-acre in-fill threshold is based on undeveloped area available (not amount of land disturbed).

For the infiltration standards, redevelopment sites are exempt. Otherwise, new residential development projects are required to infiltrate at least 90 percent of the water falling on the site and non-residential development infiltration volumes are required to be at least 60 percent.

Peak runoff rates (or peak discharge rates) refer to the maximum volume flow rate passing a particular location during a storm event. Peak discharge is typically increased with increased development as more water is collected and conveyed across impervious surfaces. For example water from two adjacent parking lots is collected and flows to a common gutter. This additive volume gathers energy as it flows downhill toward a discharge pipe. This increased volume can scour riverbanks and increase the risk for flooding. Peak discharge is typically expressed in units of volume/time (e.g., ft3/sec). Within Wisconsin's rules, the peak discharge for post-construction conditions are to be reduced to the pre-development conditions for the two-year, 24-hour storm (though some local ordinances may vary).

The peak discharge standards do not apply to:

- Sites classified as redevelopment
- Infill development less than 5 acres

For more information on Wisconsin's post-construction requirements, presented as PowerPoint presentations, visit <www.dnr.state.wi.us/org/water/wm/nps/stormwater/post-constr>.

Courtyards and landscaped areas are common features of site plans. Small modifications in drainage and plant selection can improve the water handling performance of infill projects.

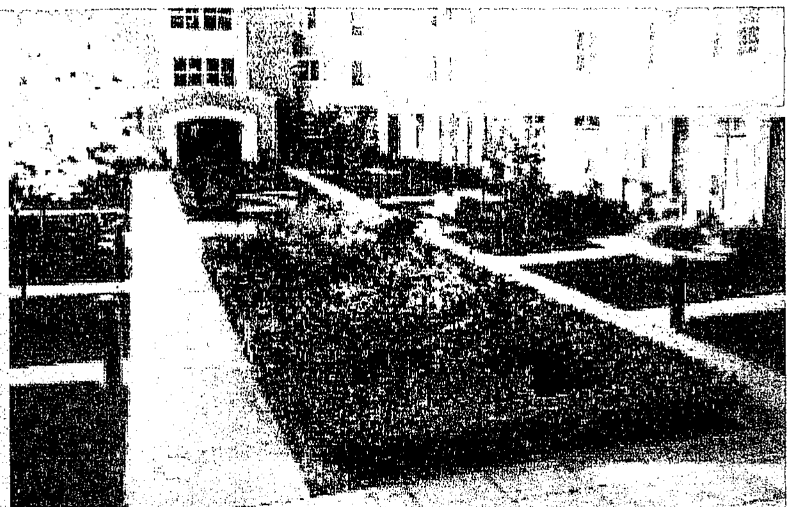


Photo: City of Portland, Washington

to support development in these targeted areas. Maryland's Smart Growth Initiative, passed in 1997, directs state infrastructure funds into PFAs. The initiative identified areas automatically included, and also allowed counties to designate certain areas within their boundaries as PFAs. Under this policy, local jurisdictions may allow development in non-PFAs, but must fund all infrastructure improvements locally. Phase II communities located in a PFA should make sure local stormwater policies complement the state plan. For example, a complementary plan would make sure that (1) comprehensive plans, zoning codes, and standards are in place to foster infill, (2) local funding investments match the state's commitment, including sewers, stormwater, and transportation, and (3) permitting processes do not pose barriers to infill.

Rather than require stormwater handling for each individual project, the city of San Diego adopted a policy in 2002 to allow infill developers to share in the cost of stormwater abatement. The Standard Urban Stormwater Mitigation Plan allows developers to contribute to stormwater mitigation that serves the entire drainage basin. Engineers estimate that individual developments projects can achieve savings of up to $40,000 by participating in a shared stormwater control program. For more detailed information on the Localized Equivalent Area Drainage program, (LEAD) visit <www.sannet.gov/stormwater> and type "Localized Equivalent Area Drainage" into the site's search engine.

Some of the best advocates for infill are developers themselves. The Center for Watershed Protection has two programs, Builders for the Bay and the Site Design Roundtable, which gather information from developers on the best ways to build stormwater-friendly developments. For more information, visit <www.cwp.org>.

Points to Consider

Lots slated for infill can be the last open spaces in a built-out community. In some instances, they may be the remaining open lots that handle urban stormwater. There is no one method for determining whether these lots should be kept open for stormwater control or developed. The local development context is a critical consideration that comes into play. Green spaces and parks serve a multitude of purposes in urban areas for aesthetic purposes, recreation, and environmental benefits.

Some lots may not be critical for natural handling of stormwater, but may be in an area with waterways that are already compromised by development-related stormwater runoff. In this case, there are an increasing number of green building techniques and low impact development (LID) options for onsite stormwater control. Developers and their landscape architects should look at common urban development features, such as courtyards, small water features, and tree planting areas for stormwater control. Since these features are likely to already be included in site plans, small design modifications to handle runoff can improve your project's performance. The Center for Watershed Protection has developed several documents under its "Smart Sites" initiative, which can be found at <www.cwp.org/smartsites.pdf>.

As discussed elsewhere in this subsection, investments from infill development may be able to support improved stormwater handling by way of gray infrastructure. Localities should look at infrastructure financing plans, and how they can be used to attract infill investments. A mitigation plan for development projects can lessen stormwater impacts related to infill. Maryland's *Guide to BMP Selection and Location* includes tables of BMPs and in which setting they perform best. See <www.mde.state.md.us/assets/document/chapter4.pdf>.

Finally, even where there is strong consensus among the stormwater engineer and other planning departments on strategies for infill, local residents may oppose any new development project in their community. In a growing number of circumstances, the arguments are based on increased stormwater runoff. Several organizations have developed tools to help design better infill projects and develop community consensus early on. In addition, the low impact and site design options listed in this document may help developers, community members, and zoning officials understand the options for handling infill development in a way that also protects the local environment. The Greenbelt Alliance in California <www.greenbelt.org> has produced *Smarter Infill* and Smart Growth America <www.smartgrowthamerica.org> has released *Choosing Our Community's Future*.

Language to Look for in Ordinances

It is important to keep in mind that the language in your city or county's stormwater ordinances and guidance will be part of a regulatory and legal framework in the same manner that zoning ordinances are. Thus, the particular wording can have implications for whether the stormwater policies will work in concert with, or against, your smart growth policies. Most communities will have to balance the need for language that is legally binding, flexible, and designed to deliver stormwater benefits to the maximum extent practicable.

Language Fostering Creation of Joint Smart Growth and Stormwater Policies

Language specifying that post-development hydrology match the pre-development hydrology: Language to this effect may foster redevelopment. Because the pre-development state of the parcel was already developed, a redevelopment project with the same lot coverage will essentially have no effect. When you write your ordinance, however, you may want to avoid confusion by specifying that the pre-development condition refers to the site immediately prior to redevelopment.

Language classifying a smart growth technique as a BMP: This language will verify that your smart growth policies are recognized as stormwater practices. Note that your guidance or ordinance may also require maintenance and operation for the BMPs. For example, if your "Fix It First" policy is adopted by reference as a stormwater BMP, the BMP maintenance requirements are also likely to apply. If you have established a BMP maintenance fund, this could establish a new source of funding for priority repairs.

Adding "prevention" of stormwater to your ordinance's purpose or goals section: Stormwater BMPs have traditionally been designed for mitigation; that is, to lessen stormwater once it is generated. Adding stormwater prevention to your goals, however, can help support the prioritization of redevelopment, compact development plans, and "Fix It First" programs.

Language that includes smart growth policy techniques in the definitions: The "Definitions" section of your ordinance is an important feature. The legal definition will establish how narrow or broad your options can be, or even what measures can be classified as BMPs. In addition, having smart growth policy terms in the definition can assist you in cross-referencing other plans, which can save time and resources. For example, many cities are exempting projects in dense, urban areas from infiltration requirements. Rather than delineate new areas, some cities are using established districts, such as "Business Improvement Districts" or "core downtown" or boundaries set in economic development plans. Adopting these districts into the "Definitions" section of your stormwater plan automatically delineates where policies apply. Even if the policy is not fully used in the ordinance or guidance during the first five-year permit, establishing the definition can serve as a placeholder as your community works out the full details.

Language that refers to design manuals: Because the stormwater management aspects of a development project can be comprised of many interrelated elements, ordinances often refer to design manuals. The reference to a manual will allow localities to develop and maintain manuals that reflect their smart growth programs. You may want to see where a local manual and/or ordinance on "traditional neighborhood design" or "Main Street Redevelopment District" can be customized to add stormwater management criteria for hydraulic sizing and performance standards.

Language Hindering Creation of Joint Smart Growth and Stormwater Policies

Language specifying that post-development hydrology match the pre-development hydrology: This language, which can help incentivize redevelopment as noted above, can block infill on undeveloped sites or smart growth on greenfields sites. Make sure there is flexibility within your stormwater and urban design plans so that the requirement for maintaining natural hydrology delivers projects that work in all contexts within a watershed.

Language requiring that BMPs replicate natural systems or non-structural natural BMPs: This might be a desired strategy in rural areas or those with pristine water resources. If this is a strict statement that covers all development projects in your city, county, or township, however, your community might face difficulties in directing growth to areas specifically targeted for a higher intensity of development. In addition, some strategies for replicating natural systems require large areas of land for infiltration or filtration of pollutants, which might consume land needed in a traditional town center or new urbanist plan to create a compact, walkable town center. Make sure there is flexibility so that there are options for stormwater management that are context-sensitive.

Language that classifies the intensity of control based on "housing units per acre": Most land use plans classify the intensity of residential development based on housing units per acre. This system is based on zoning conventions that tend to separate uses, and hence, can disperse development. Stormwater regulations based on units per acre will not only reinforce this system, but are likely to miss the importance of looking at water impacts on a "per unit" basis. Many watershed managers are faced with growth estimates over the next decade that range from several hundred households, to thousands of new households. Looking solely at "housing units per acre" on given acreage within a watershed may produce an unrealistically low picture of the planning and investment needed. Looking at impacts on a "per unit" basis may help communities—in particular, growing communities—fully assess water impacts of expected growth in total number of households in the watershed.

Language to tie priority funding to adoption of a model ordinance: Many states are developing model ordinances for local communities as a way to reduce the resources needed to develop and implement NPDES permit programs. These model ordinances are, by their nature, written to a minimum level of compliance, and written broadly as to be applicable in many different environmental settings. As an alternative to a model ordinance, states are also allowing communities to develop innovative alternative plans. When priority funding is given for adoption of the model ordinance, there is less incentive for a community to choose options for developing innovative and multi-objective plans. In addition, many communities will likely choose an option that is as simple and spelled-out as possible. By developing specialized manuals for Traditional Neighborhood Design and redevelopment areas, localities have a ready-to-use option for smart growth. Localities and state should look for ways to make a variety of options attractive through technical assistance and/or funding priorities.

Impervious coverage limitations: Many state and local permits have incorporated impervious surface limitations (or lot coverage limitations) based on studies that show that a watershed begins to deteriorate when 7 to 10 percent of the watershed is covered by impervious surface. This concept has been translated to the site level through ordinances that limit coverage of rooftops and parking to no more than 10 to 20 percent of the site. While this may be an effective strategy in some circumstances (for example, to protect pristine waters), in others, this type of ordinance serves to spread out development even more. Larger lots are needed for all development projects, which serves to extend the distances among uses. This, in turn, requires longer stretches of roadway and more water and sewer infrastructure per unit of development.

3. Redevelopment

Definition

Redevelopment is development of a site that has been previously developed and is typically covered with impervious or compacted surface. For purposes of this subsection, the reader can assume that the lot is covered with compacted or impervious surface and has minimal to no value in handling stormwater. These projects can include development of vacant buildings, lots where a building has been torn down and replaced with gravel parking lots, or older malls.

Who Do I Talk to About Redevelopment Plans?

In most instances, redevelopment is left to market forces. Developers and real estate investors seek out available property and either redevelop by-right or petition for a variance or rezoning. In other jurisdictions, special entities are formed to foster redevelopment. There are often barriers to redevelopment, including complex approval processes and the perception from lenders that the deal will pose more risk than new development projects.

Thus the best resources for learning about redevelopment plans can be private sector organizations, or public/private partnerships. Economic entities, such as redevelopment authorities, "Main Street" programs and brownfields offices, often work to line up financing, zoning reforms, shared parking arrangements, and other incentives to overcome the barriers and perceptions that suppress market interest. Talk to your economic development director, chamber of commerce, or city manager to see if there are established redevelopment districts that can be added to your stormwater management plans. If you are the head of a redevelopment agency, talk to local experts on land development to develop scenarios of watershed growth. In this way, you can present not only the economic benefits of redevelopment, but also the regional water benefits that can accrue from successful implementation of your Main Street or brownfields program.

As a stakeholder in the stormwater process, you may also want to consult with commercial real estate brokers to investigate why a commercial district, mall, or older downtown is underperforming, and what steps are likely to revive interest.

Examples of programs that you can ask about include:

Vacant Property Reform: According to the National Vacant Properties Campaign, vacant and abandoned properties occupy about 15 percent of the area of a typical large city—more than 12,000 acres on average. Vacant property reforms are designed to encourage the redevelopment of vacant properties, allowing the utilization of existing buildings in potentially desirable urban and suburban locations. For more information, see <www.vacantproperties.org>. The International City/County Managers Association has researched and reported on successful local efforts to bring vacant commercial and residential properties back into use. For more information, see <www.icma.org/vacantproperties>.

Greyfields: Greyfields are a subcategory of vacant or underperforming properties. Greyfields are large, previously developed properties, such as older shopping malls and warehouses. These sites tend to be large and well-served by transportation and stormwater infrastructure. These properties differ from brownfields in that they are not contaminated or perceived to be contaminated. To see if your community is working on a redevelopment strategy for old malls or other greyfield sites, contact the department of economic development or the local chamber of commerce. This strategy may include mixed-use rezoning, enhancing transportation on the site, and/or redevelopment incentives. Because these sites are so large and are not contaminated, you may be able to negotiate for better control of stormwater on site, and thus increase the stormwater benefits of the redevelopment project. The Congress for the New Urbanism published *Greyfields into Goldfields*, which presents information on common reasons behind the decline in malls and large properties and development options for reusing the sites. See <www.cnu.org/cnu_reports/Executive_summary.pdf>.

Renovation Codes: Renovation, or rehabilitation, codes are commonly developed to replace inflexible building codes with a set of coordinated standards for renovation and rehabilitation in older areas. For example, renovation of an old downtown might be prohibitively expensive, or impossible under building codes created for new development. Renovation codes meet safety objectives while setting workable standards for renovation. Renovation codes also help towns revitalize the economy of their downtowns, while relieving development pressure on greenfield sites (and thus retaining the stormwater benefits of open space). The United States Department of Housing and Urban Development published a report, *Smart Codes in Your Community: A Guide to Building Rehabilitation Codes*, describing various redevelopment codes and examples of rehabilitation codes from across the country. See <http://www.huduser.org/publications/destech/smartcodes.html>. If your community or state offers support for renovation and rehabilitation, also check to see if historic tax credits are allowed, and count this toward your stormwater credit for redevelopment. Check with your historic preservation office or local nonprofits that deal with historic preservation.

Typical Costs

The costs of redevelopment are distributed among several stakeholders. For a city or county, fostering redevelopment can include (1) the costs of redevelopment planning and stakeholder outreach, (2) the costs of any incentives provided, (3) upgrading and repair of existing street and water infrastructure, and (4) staff time if specific programs have been established. These costs, however, cannot be appraised without looking at the costs associated with vacant or underused commercial and residential properties. The Vacant Properties campaign has compiled information on these costs and are available at <www.vacantproperties.org>.

For developers, redevelopment projects in already-developed areas are typically more complex, and thus can be more expensive. These developers must work with existing street and circulation patterns, building configurations, and zoning and regulatory codes, many of which are decades or even centuries old. Developers look at the time and cost involved to see if projects "pencil out" economically. Local incentives and regulations play into cost, including stormwater management. Review your smart growth plan (and state programs) to see if funding mechanisms, open space and park funds, tax incentives, or permit review incentives are available. When packaged strategically, these incentives may serve not only as economic development incentives, but stormwater program incentives as well.

Measurable Goals

Since redevelopment projects are discrete and are typically tracked through permits, stormwater managers may be able to use databases that are already in use. Since many stormwater consultants are establishing tracking software, work with them to establish new fields to track the impervious surface reused through redevelopment. One example of a measurable goal would be to create an inventory of vacant properties and set goals for redeveloping them.

As noted in the previous section, you may also be able to track the amount of impervious surface avoided through your redevelopment programs. This approach would translate how the square footage, building footprint, parking and associated infrastructure would compare under conventional development standards elsewhere in the watershed. As a first step, the stormwater or planning office would need to estimate (1) where the development might go were it not for redevelopment programs, (2) the average parameters for conventional development (e.g., likely number of parking spaces, new road and access designs), and (3) any other secondary impacts that might come from new growth.

Examples

Comparing build-out scenarios was used to assess the transportation and water and air quality impacts of Atlantic Station, a brownfields redevelopment project in Atlanta.[13] The site design for Atlantic Station, located on a former steel factory, includes several stormwater improvements. The developer, Jacoby Development Inc., built stormwater handling features on the site, upgraded the storm and sanitary sewer network for the project, and addressed groundwater contamination.

As part of EPA's analysis, the Agency compared how the same intensity of development would perform if built according to conventional development standards in other parts of the Atlantic metropolitan region farther from the urban core.

This lake, located in the central part of the Atlantic Station redevelopment project in Atlanta, Georgia, is a development amenity, but also assists in stormwater management.

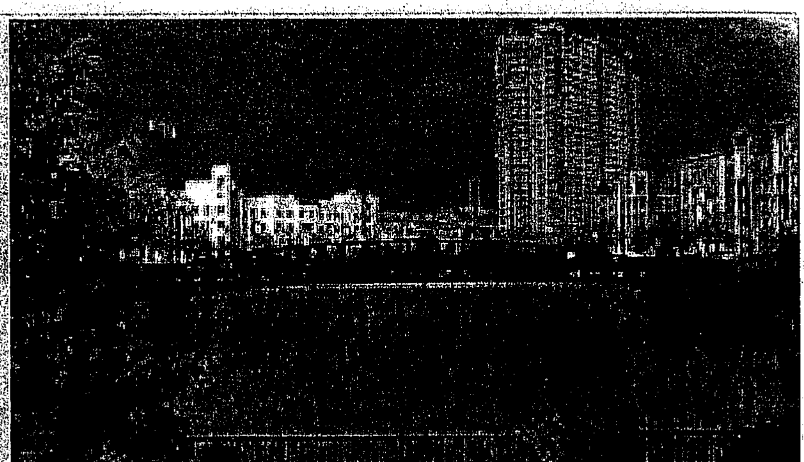


Photo: Paul Muldawer

Compared to a greenfields site, the redevelopment scenario had lower total phosphorous and nitrogen loadings, as well as reduced volume. In some cases, the comparative reductions were orders of magnitude lower. To learn more about this project, visit <www.epa.gov/projectxl/atlantic/index.htm>.

Points to Consider

Most of the "Points to Consider" listed under the previous section on "Infill Development" also apply. As noted above, many cities and counties are adding onsite water handling requirements to all development and redevelopment projects. Even where there is flexibility in stormwater ordinances, cities and counties should make sure that the BMP requirements for all projects are established on a "level playing field." Stormwater engineers and planners should compare the costs, the permitting process, and predictability of the BMPs required for development and redevelopment projects. For example, stormwater management programs that rely heavily on infiltration techniques might tilt the playing field in favor of large, dispersed projects on less expensive land. Typically, this land is located farther out in undeveloped reaches of the watershed, where infiltration on a larger scale is already taking place. Even with requirements for infiltration on site, the disturbance that takes place can be a net loss for the watershed. Thus, stormwater and watershed managers may want to assess the balance of requirements and incentives to make sure stormwater rules are not inadvertently pushing development to undeveloped land.

4. Development Districts

Definition

Development districts (or in some cases special zoning districts) are created to achieve comprehensive planning and urban design objectives in a specified area. While the previous subsections reviewed policies for individual sites and smaller projects, development districts are characterized by a larger site area and the need for complex and coordinated rezoning, transportation, and planning efforts. Examples of special zoning districts include transit oriented zoning districts (TOD), business improvement districts (BIDs), new urbanist projects, traditional neighborhood development (TNDs), brownfields redevelopment, and "Main Street" revitalization districts.

Who Do I Talk to About District Plans?

If an area is incorporated, any such district would be found in the city's zoning ordinance. If an area is unincorporated, county zoning applies. In some cases, the zoning regulations carefully delineate the sub-area plans or special districts and show them on a map.

If you are in a county that does not have zoning, or has not yet reviewed zoning codes for redevelopment areas, your locality may have developed special plans for certain areas, for example a BID or "Main Street" redevelopment plan. Check to see if there is a document listing specific policies or planned zoning changes related to development or redevelopment in the district. Many of the policies listed in Subsection 2 (Infill

Development) might be listed and can be included in your SWMP.

Innovations in zoning and building codes have emerged under a variety of names. The Smart Code, TND codes, form-based codes, unified development ordinances (UDOs), and model development codes are examples. These codes may apply to the entire municipality, to new development only, or in the form of an overlay zone. The Congress for New Urbanism has collected examples of various code innovations at <www.cnu.org/pdf/code_catalog_8-1-01.pdf>.

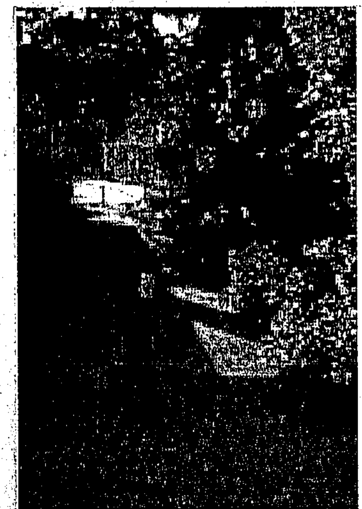


Photo: www.pedbikeimages.org/Dan Burden

This path allows safe pedestrian and bike passage, but is also designed for access by emergency and service vehicles.

In reviewing codes with your local planning office or economic development department, make sure that the *all* pieces are in place to deliver on the smart growth benefits. For example a unified development ordinance might require sidewalks on both sides of the street; however, if state transportation and local zoning policies result in highly separated uses with mandated turning lanes and wide intersections, pedestrian trips may be reduced, if not eliminated. The stormwater benefits are likewise diminished. Thus, you may need to consult with the zoning and planning office, together with a transportation engineer. If one set of codes supercedes another, you may want to consult with the city or county manager to find flexibility and list all the benefits, including stormwater, that come from a smart growth development district.

Subdivision codes are a common method incorporated and unincorporated communities use to control development. Most subdivision codes establish how many housing units can be built by-right on undeveloped land. Over time, subdivision codes have evolved to control development-related aspects such as street widths, septic requirements, and/or infrastructure planning. Some subdivisions may also be governed under drainage districts, which place limits on impervious surface coverage and map development restrictions in areas of significant drainage flows. In some cases, subdivision requirements will govern the street network and control the number of connections required between the subdivision and surrounding parcels (see Subsection 8, Smart Growth Street Designs for more information). Consult your city or county's engineer or planning office to see if smart growth policies have been added to your subdivision codes.

Check to see if your community has formed public/private partnerships or alliances to facilitate planning and implementation for these districts. Also check with a local historical society, the downtown business association, or the local chamber of commerce to see if they are aware of special planning or economic development districts.

Brownfields are properties with real or perceived contamination from prior uses and, in some cases, are classified as districts for the purposes of cleanup, financial incentives, and coordinated redevelopment. Larger brownfields can include former military bases, transportation facilities, and institutions. These large properties are often located in areas near existing transportation and infrastructure. The larger parcels pose opportunities to redesign a development program that includes smart growth features, like multi-modal street design, advantageous use of existing transportation routes, and open space. EPA estimates that for every acre of brownfields redevelopment, 4.5 acres of greenfields can be preserved.[14] Check to see if your community has developed plans for brownfields identification, cleanup and/or development plans. There may be opportunities to design large scale, onsite stormwater handling in areas where the contamination will not be transported after redevelopment has taken place.

Stormwater Benefits

As noted in the previous subsections, special zoning districts can limit overall stormwater runoff by directing development away from greenfields at the urban fringe into existing urban areas. (See Subsections 2, Infill Development, and 3, Redevelopment, for further information on the impacts of encouraging infill.) Coordination of planning, investment, and infrastructure for a district can also result in a more efficient site plan. Development decisions are made at a larger coordinated scale, which can facilitate efficient street layouts, a smaller footprint for parking facilities, and less expensive options for collecting and handling stormwater for the district.

In addition, mixed-use districts can support a wider variety of transportation options, which lessens the impacts of transportation on water quality. Auto emissions have deleterious effects through deposition of exhaust and accumulation of automotive related materials (brake linings and tire tread wear) that are carried into waterways through stormwater runoff.

A 2004 study conducted by Asad J. Khattak and Daniel Rodriguez of the University of North Carolina, Chapel Hill, suggests that households in the neo-traditional development substitute driving trips with walking trips. The study examined differences in travel behavior in a matched pair of neighborhoods (one conventional and one neo-traditional) in Chapel Hill and Carrboro, North Carolina. The survey and study of 453 households suggest that single-family households in the neo-traditional development make a similar number of total trips, but significantly fewer automobile trips, fewer external trips, and shorter trips than households in the conventional neighborhood, even after controlling for demographic characteristics of the households and for resident self-selection.[15] One term that transportation professionals often use to describe trip-making within a set district is "internal capture rate." When urban planners talk about a high internal capture rate for a proposed district, this forecast relates to a higher percentage of multi-modal and/or combined trips within the district. This is something stormwater professionals should look for when evaluating plans.

Paved Area per Dwelling Unit – a Comparison

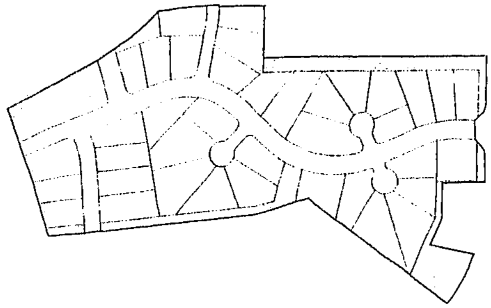


Image: Tom Low, Duany Plater-Zyberk

Conventional Residential Subdivision

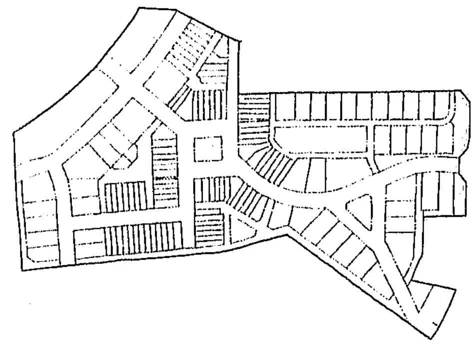


Image: Tom Low, Duany Plater-Zyberk

Mixed Use, Traditional Neighborhood Design

Vermillion is a traditional neighborhood outside Huntersville, North Carolina. The town enacted a TND ordinance to coordinate the approval process for TNDs. The two maps were drawn to compare the TND design and a more conventional, residential-only design.

In the new urbanist street plan, the greater part of the paved areas is taken up by narrow 18 feet roadway widths, whereas the conventional plan relies on wider 30 feet streets. Although the roadway area is higher in the TND plan, the street component per dwelling unit is far less, as indicated in the following tables.

Conventional Design

- 38 single family homes

Street Width (feet)	Street Length (feet)	Street Imperviousness (ft^2)
18	275	4,950
24	350	8,400
30	2111	63,330
		76,680
76,680/38 dwellings = 2,018 square feet street imperviousness/dwelling unit		

Traditional Neighborhood Design

- 40 single family homes
- 16 studio apartments
- 16 live/work dwellings
- 74 townhouses

Total 146 residential dwelling units

- One office building (4,400 square feet)
- Two medium sized office buildings (30,000 square feet total)
- Three smaller commercial buildings (15,000 square feet total)
- One restaurant (5,000 square feet)
- One church (10,000 square feet)

Street Width (feet)	Street Length (feet)	Street Imperviousness (ft^2)
18	3,270	58,860
24	750	18,000
30	525	15,750
		92,610
92,610/146 dwellings = 634 square feet street imperviousness/dwelling unit		

The analysis did not look at sidewalk lengths, or the street imperviousness related to commercial buildings.[16]

Development and redevelopment plans that are based on districts might also allow stormwater officials to meet requirements under the Illicit Connection Minimum Control under Phase II. Many large redevelopment parcels are near waterways and offer the potential to correct stormwater and infrastructure problems. Many illicit connections are found in older manufacturing districts, so you may be able to also meet requirements to find and eliminate illicit discharges.

Finally, the stormwater performance of a site is the result of, or enhanced by, the additive effect of several redevelopment policies. For example, in a TOD district, policies to require higher density development are combined with maximum setback rules and reduced parking requirements. All three of these policies work together to support transit use and higher density projects on a smaller development footprint. It is worth noting that under current practice, development districts such as office and industrial parks do not carry these advantages. The dispersed arrangement, large surface parking lots and predominance of a single use (e.g., office only) serve to spread development—and the associated impervious surfaces—out further.

Typical Costs

For the public sector, the cost of planning a special district and setting or revising zoning is the staff time required to research, adopt, and implement the new codes. Some communities hire consultants to help gather and coordinate stakeholder input, draft design alternatives, and create final plans. The range of costs varies. You may be able to tap the expertise of a local university or nonprofit at a lower cost for gathering input and narrowing the scope of items that need the specialized skills of a consultant.

While brownfields redevelopment can be costly, new regulations and programs are in place to assist localities and developers. The variety of activities related to financing and redeveloping brownfields sites is beyond the scope of this publication, but you may have brownfields redevelopment activity underway which you can cite in your stormwater guidance materials. EPA has a comprehensive site on how to remediate, market, and develop brownfields sites at <www.epa.gov/swerosps/bf/index.html>.

Some communities may already have design manuals in place for transit districts, TNDs, or new urbanist communities. These can serve as a starting point for developing a joint smart growth/stormwater BMP manual. These manuals typically include detailed information on streets, building envelopes, the use mix, and transportation connections. Stormwater, zoning, and planning departments may be able to cost-effectively create a BMP manual for development districts from work that has already been completed. For example, a stormwater engineer could take the city's manual on TND and insert information on siting stormwater handling facilities within the TND, on using water features for stormwater control, and sizing criteria for various BMPs and performance criteria at the site and neighborhood scales.

Measurable Goals

For a jurisdiction without comprehensive zoning for development districts, a short-term goal could include adoption of a special district ordinance. For a jurisdiction that already has special zoning districts in place, goals would depend on the type of ordinance adopted. For jurisdictions with TOD zoning, a goal might be to raise the percentage of new development built in already-developed areas by a certain percent over a specified time period. If detailed information is available on transit use, one can estimate the reduction in automobile-related deposition and runoff pollution.

As listed above, communities may also want to estimate stormwater performance of smart growth projects not only on the site level, but on the watershed or regional level as well. Redevelopment of an entirely developed site basically results in no net increase in stormwater at the local level, but also absorbs development demand that would otherwise result in the addition of impervious cover in an undeveloped portion of the watershed. Subsection 1, Regional Planning gives information on the methods for comparing smart growth and conventional development plans.

Examples

San Diego has launched a "City of Villages" plan to direct development via infill and redevelopment to certain neighborhoods. The planning update and the stormwater management cross-reference the City of Villages infill plan as a water strategy. To see more on the planning efforts, visit <www.sandiego.gov/cityofvillages>. For more on the Urban Runoff Management Plan, visit <www.sandiego.gov/stormwater>.

LEED Neighborhood Design

Check with your zoning or environmental works department to see if your locality has adopted the U.S. Green Building Council's (USGBC's) scorecards. These scorecards, called LEED (for Leadership in Environmental and Energy Design), contain rating systems for development and redevelopment projects. USGBC is developing a new scorecard called LEED Neighborhood Design – or LEED ND. This scorecard includes not only green aspects of individual buildings, but of their location as well. Thus, the scorecard takes into consideration the smart growth principles based on transportation options, a mix of housing types, and connections to the broader community. LEED scorecards, including LEED ND, include rating points for how the project or district handles stormwater, and might provide a template for measuring your locality's performance under NPDES. For more information on the LEED scorecards, visit <www.usgbc.org/leed/leed_main.asp>.

An example of creative stormwater financing comes from **Elm Grove, Wisconsin.** Flooding has been a significant problem for the city—in particular, for the downtown area. In 2001, the city developed an economic development plan for the downtown, with a focus on reducing the flooding. To address the flooding issue, the city has developed a stormwater mitigation plan with many elements, including restoration of concrete-lined creeks to their natural state, improving stormwater retention areas and redesigning the city's park with water control in mind. Because the flood management plan is expected to reduce the size of the 100-year floodplain, properties that are no longer in the floodplain as a result of the improvements will increase in value. The town is creating a TIF district to capture this value, and invest in the targeted stormwater improvements. The town is also creating a stormwater utility because the monies raised through the TIF are not expected to cover the costs of all of the needed improvements. The town is coordinating the water planning with the revised Master Plan for its downtown, which will include retaining a small town feel, creating a pedestrian friendly environment, and incentivizing redevelopment in the downtown area. For more information, visit <www.elmgrovewi.org>.

The Trust for Historic Preservation sponsors the Main Street Program to spur investment in older downtowns. Enterprise Zones and Elm Street Programs are other programs established to attract investment to older downtowns. These programs are evidence of growing interest in historic areas and what they offer, such as unique older buildings, a walkable layout, and economic potential. Stormwater professionals should look to these programs in their communities as a way to manage stormwater runoff within their watersheds. To learn about the specific policies and programs, visit <www.mainstreet.org>.

The **Mountain View, California**, transit station, called The Crossings, is an example of how redevelopment of a greyfields site into a transit district can include better stormwater management. Prior to redevelopment, the 16-acre site was 98 percent impervious cover and home to an underperforming shopping mall. Because the California Department of Transportation planned to build a commuter rail station immediately adjacent to the site, the city of Mountain View envisioned making the station a success through a higher density and mixed-use development program. As redevelopment occurred, planners were able to build in onsite handling of stormwater for more than 45 percent of the site. Open spaces designed to absorb water are complemented by compact building sites, a grid of narrow streets and a space-efficient parking plan. For this and other case studies, visit the Natural Resources Defense Council's "Stormwater Strategies" at <www.nrdc.org/water/pollution/storm/stoinx.asp>.

More information on the transportation and land use performance of the station area in Mountain View can be found at <transitorienteddevelopment.dot.ca.gov>; follow the links to "The Crossings."

Points to Consider

One type of special district that requires particular attention is the use of impervious surface coverage districts. Impervious surface zoning districts generally set maximum ratios on the amount of impervious surface within a zone or, more commonly, on a parcel. For example, an ordinance might state that no more than 20 percent of a lot may be covered with impervious surfaces such as rooftops, driveways, or accessory buildings. Often, the purpose behind impervious surface districts

Photo: EPA

A mixed-use district is used at The Crossings, in Mountain View, California.

is based on studies that show watershed decline begins once impervious surface coverage exceeds 10 percent.[17] The 10-percent figure has been applied to the individual site level within the watershed, suggesting that limiting development to lower densities that only cover a portion of the site will translate across the watershed to more pervious surfaces for stormwater control and preserved ecological function.

However, application of an impervious surface district on a parcel-by-parcel basis, might not help meet stormwater objectives, and in fact, might result in worsened water quality, particularly on a watershed scale. The following are points to consider regarding impervious surface districts that apply only to the site level:

Impervious surface ordinances consider only site cover, not the ultimate goal of reducing stormwater runoff volumes: For example, suppose a homeowner would like to build an addition to his/her house, which is located in an older urban area that the city has designated for economic redevelopment. The homeowner also would like to disconnect the downspouts and develop a rain garden and other features to handle all of the stormwater on site. An impervious surface code, read strictly, would prohibit that homeowner from building the addition, even though the homeowner would improve stormwater management on the lot. The impervious surface district has the effect of creating a low-density district, which may run counter to a community's wish to accommodate more density in certain neighborhoods to make use of transit, foster redevelopment, or respond to market demand.

Much of the "pervious" surface in low-density development acts like impervious surface for handling stormwater: Development practices can involve wholesale grading of a site, removal of topsoil, severe erosion during construction, compaction by heavy equipment, and filling of depressions. Research now shows that the runoff from highly compacted lawns is almost as high as runoff from paved surfaces.[18] The turfgrass planted in a typical new residential project does little to reverse the impacts to the soil by construction. Further, turfgrasses have shallow roots that do not provide the same soil anchoring, water uptake, and other ecological processes as deep-rooted native grasses and plants.

Low-density developments tend to be accompanied by more offsite impervious infrastructure: Development in a watershed is not simply the sum of the parcels within it. Rather, total impervious area in a watershed is the sum of site developments plus all of the infrastructure (e.g., water utility, transportation) supporting those sites. For example, the hard cover of a parking space with dimensions of 18 feet by 9 feet is not the only imperviousness associated with that space. Drive or access aisles are also typically coded into parking standards; a parking lot with 90-degree parking typically is served by a 24-foot drive aisle that spans the length of the parking lot and ties into other access lanes. Additionally, many modern street codes require additional lanes for turning, deceleration, and service lanes. An impervious surface coverage district that considers only development of individual sites might miss much of the impervious surface that is leading to degradation of water quality in the entire watershed.

Growth is coming to the region; limiting density on a given site doesn't eliminate that growth. Density limits are responses to—and attempts to manage—growth: Yet these limits do not, in fact, manage growth; they only manage the growth on the density-limited area. The rest of the growth that was going to come to the region still comes, but spreads throughout or across the watershed.

From a water resource protection perspective, defining the balance of developed areas and open space requires a broader look at watershed management, rather than limits on a parcel-by-parcel basis. A first step is to plan for strategic preservation of continuous tracts of open space. Second, preservation of critical ecological areas such as riparian corridors, stream buffers, flood plains, and wetlands is needed. These parcels are of critical importance in developed areas to absorb and filter stormwater. Third, for land that is to be developed, smart growth strategies such as higher density and more compact development serve to disturb less land and accommodate more development. As mentioned elsewhere in this publication, redevelopment sites are particularly attractive when considering development and stormwater mitigation options since they use already-developed sites and are likely to use existing infrastructure.

There is a spirited debate about the performance of impervious surface limitations and how they should be structured to achieve the intended water quality goals. One result of the debate is a better focus on comprehensive strategies needed in a watershed. Organizations like the Center for Watershed Protection <www.cwp.org> and Project NEMO's research division <nemo.uconn.edu/impervious_surfaces/index.htm> are fine-tuning the mapping, measurement, and characterization of impervious surface coverage and the relationship to water quality.

If an impervious surface special district is in your plan, one suggestion is to make sure the program looks at a watershed scale and the individual parcel, and includes all supporting impervious surfaces in the watershed. Another strategy involves modifying or eliminating the coverage limitations for certain districts to which you want to direct growth. You may want to conduct a survey of imperviousness per unit of development for conventional and smart growth plans. Impervious surface limitations may make sense in one part of the watershed (for example in headwater areas) or when applied watershed wide, but only when carefully reviewed with other subwatershed and subareas plans where redevelopment and development is desired.

If your locality has a smart growth plan, make sure your impervious surface zoning does not act as a barrier to that plan. If your plan calls for higher density in certain districts, such as TOD districts and downtown redevelopment areas, then your impervious surface district should have enough flexibility to allow such density. Many areas are exploring the possibility of trading systems that coordinate development and preservation efforts. Trading programs might be found within a total maximum daily load (TMDL) program, for trading of impervious surfaces on a watershed-wide basis, or through a "payment in lieu of" program for installing BMPs. EPA has launched efforts to facilitate trading as a way to improve water quality. To learn more about EPA policy and the steps involved in establishing a trading program, visit <www.epa.gov/OWOW/watershed/trading.htm>.

TMDLs, Stormwater, and Smart Growth

Across the country, more than 40 percent of waterways are impaired by pollutants, sediment, temperature (typically heat), and nutrients. These waterways can be stream segments, bays, estuaries, and lakes. Once a waterway is listed as an impaired waterbody, localities are responsible for developing a "budget" for how much of a pollutant load the waterbody can experience. This budget is referred to as a TMDL, or total maximum daily load. A process typically follows to identify major sources (e.g., agriculture, urban runoff) and allocate a portion of the pollutant load to each source. The goal of a TMDL program is to restore a waterway by reducing pollutant sources. Thus, sources often face reductions in how much pollutant they contribute.

Stormwater can be a major contributor to impairments due to the heat, nutrients, metals, and other pollutants carried in runoff. Thus, reducing stormwater runoff in areas with impaired waterbodies is often at the center of the TMDL process.

As discussed throughout this document, smart growth techniques can help prevent and/or reduce stormwater volume and the pollutants carried within the runoff. In other words, smart growth can offer load reductions. By encouraging designs with lower impacts, the locality has taken steps not only to lessen development's effect related to transportation and infiltration, but also to provide an incremental reduction in the pollutant load from stormwater discharges. Though not required, some states and localities are including budgets within TMDLs for future growth. Communities that adopt growth management strategies that encourage smart growth and discourage sprawl are in a better position to control pollutant loadings from stormwater discharges, soil erosion, wastewater treatment systems, and many other sources of pollutants.

Some states have expressed concern that implementation of TMDLs could impede smart growth strategies because TMDLs will prohibit additional sources, which is assumed to be a prohibition on redevelopment and infill for urban areas. The fear is that developers will be inclined to focus their proposals on "greenfields" on the urban fringe, where TMDLs are not in place. Consider, however, that (1) many vacant and unused properties in urban cores already are largely impervious as a result of paving and soil compaction, so putting new buildings on these sites is unlikely to make runoff outcomes worse, (2) as described elsewhere in this publication, green building and site design options present the potential for actually reducing runoff volume and pollutant loadings from infill and redevelopment sites, and (3) greenfields development projects commonly have their own stormwater requirements so that a developer of any site will need to think about appropriate controls.

Photo: NRCS

5. Tree and Canopy Programs

Definition

Urban forestry programs are not typically considered stand-alone smart growth policies; however, tree programs are increasingly appearing as elements of larger urban design plans for landscaping or aesthetic purposes. In addition, tree policies are evolving to include abatement of urban heat island effects, or as part of transportation plans to improve the pedestrian environment. There are different types of plans and ordinances, from those that protect historically significant trees to tree planting programs. Street tree ordinances generally cover the planting and removal of trees within the public right-of-way.

These new urban forestry policies are also evolving to target tree canopy and shade cover, rather than policies that focus on numbers of individual trees. In other communities, trees are becoming part of the "public utility" as new methods are developed to measure and account for the environmental attributes of mature trees. The "utility" approach also recognizes that trees, like power lines and pipes, require maintenance and have costs associated with that maintenance. Whether it's the pedestrian environment, aesthetics, or air quality, the result of an effective urban forestry policy translates into stormwater benefits.

Who Do I Talk to About Tree and Canopy Programs?

Tree ordinances are typically overseen by public works departments or departments of environmental quality; however, also check with your local extension agent. The International Society of Arboriculture has a Web site describing the development, implementation, and evaluation of tree ordinances; go to <www.isa-arbor.com> and type "ordinances" into the site's search engine. Scenic America also lists a model tree ordinance, at <www.scenic.org>. American Forests' Web site at <www.americanforests.org> tracks tree policies and ordinances, as well as innovations in technology, research, and non-regulatory methods for supporting urban forestry.

Stormwater Benefits

A well maintained tree canopy can provide a variety of environmental benefits. Trees provide erosion control and help reduce the costs of structural stormwater management, including land acquisition costs and construction of stormwater retention facilities. Strategically preserving or planting trees along urban rivers, streams, and creeks can reduce water temperatures. Increased temperatures affect certain native aquatic species, can increase nuisance algae populations, and impact commercial activities that rely on stable water temperatures for recreation, industrial use, or aesthetics. Tree canopy intercepts rainwater, which provides for gradual release of rainwater into streams, thereby preventing flooding, filtering toxins and impurities, and extending water availability into dry months when it is most needed.

Examples from selected cities include:

- At a south **Miami** residential study site the existing tree canopy reduces stormwater runoff by 15 percent.[19]

On-street parking can be coupled with tree wells in a downtown setting.

- In Milwaukee, the existing tree canopy cover reduces stormwater flow by up to 22 percent and provides the city an estimated $15.4 million in benefits. On average, trees in Milwaukee sample sites reduced total stormwater runoff volume by 5.5 percent and reduce peak flow by 9.4 percent. At the residential study site, the 42 percent existing tree canopy reduces stormwater runoff by 22 percent. If all trees in the Milwaukee study were removed, the additional stormwater flow would be enough to require the construction of an estimated 357,083 cubic feet of retention capacity valued at approximately $15.4 million.

For information on other environmental benefits from trees, visit <www.treesatlanta.org>.

Typical Costs

Tree programs and ordinances have costs mainly associated with development, implementation, and enforcement. Maintenance of older trees can be expensive, particularly since the goal of your program is to nurture trees to maturity for maximum stormwater benefit. When these costs are considered as part of a community's stormwater infrastructure, however, they may prove worthwhile when compared to other water control expenses. Garland, Texas, used American Forests' software package CITYGreen to measure the cost savings associated with its tree canopy. Garland's trees provide 19 million cubic feet in avoided storage (for the average maximum two-year 24-hour storm event). The city estimated that it saves $2.8 million annually, calculating the cost of construction funding over the 30-year life of a facility.[20]

Measurable Goals

Short-term goals can include the establishment of a tree program that tracks the number of trees that have been saved or the number of trees planted in your jurisdiction.

As noted previously, maximum stormwater benefits come from tree canopy cover. Urban forest groups have established the environmental performance of tree cover. Software programs can help establish your baseline tree canopy and estimate the dollar value of the services provided to a community by its tree cover. Establishing a baseline and tracking cover with a software package can translate into numeric expressions of stormwater performance. For more information on one such program CITYGreen, visit <www.americanforests.org/download.php?file=/graytogreen/stormwater.pdf>.

Examples

The U.S. Department of Agriculture's U.S. **Forest Service–Southern Region** maintains information on trees and tree cover, including research, PowerPoint presentations, and model tree programs at <www.urbanforestrysouth.org>.

The **City of Roanoke, Virginia**, used CITYGreen to measure cost savings associated with its tree canopy. Roanoke's 32 percent tree canopy provides 64 million cubic feet in stormwater retention capacity, valued at $128 million (based on construction costs estimate at $2 per cubic foot). Based on the study results, the city council passed a 40 percent tree canopy goal as part of the city's comprehensive plan.

Points to Consider

Different trees have different absorption rates, growing condition needs, growth rates and life spans. Consult an arborist to determine which trees will suit the needs of your community. In the Pacific Northwest, Metro (Portland Oregon's regional government) has published a guide to the stormwater benefits associated with different trees. For specific interception rates for different types of trees and analysis of the benefits of different tree species, see *Trees for Green Streets: An Illustrated Guide*, (order from <www.metro-region.org/article.cfm?articleid=263>). Note that many climates in the United States are too arid to support a full canopy; these areas can use xeriscaping and other landscaping means to control runoff. Additionally, deciduous trees are far less effective at capturing stormwater once they shed their leaves in the winter.

When developing a tree ordinance, clearly outline your goals, methods of coordination and enforcement, and evaluation procedures. At least one tree ordinance has been successfully challenged in court as unenforceable by a developer because the language was too vague. In 1999, a Fulton County Superior Court Judge ruled in favor of developer against the city of Atlanta because a section of the city's tree ordinance lacked "sufficient" objective standards.

If you include urban forestry in your stormwater program as a BMP, think long term about maintenance requirements and be creative in finding funds for maintenance. If there are funds dedicated to funding all types of stormwater BMP maintenance, consider using these funds for tree pruning, tree care, and replacement programs. The state of Pennsylvania has proposed a BMP maintenance program that allows developers to pay a fee to cover maintenance for 10 years. For urban forestry programs, this can be an effective funding mechanism for getting a tree program started.

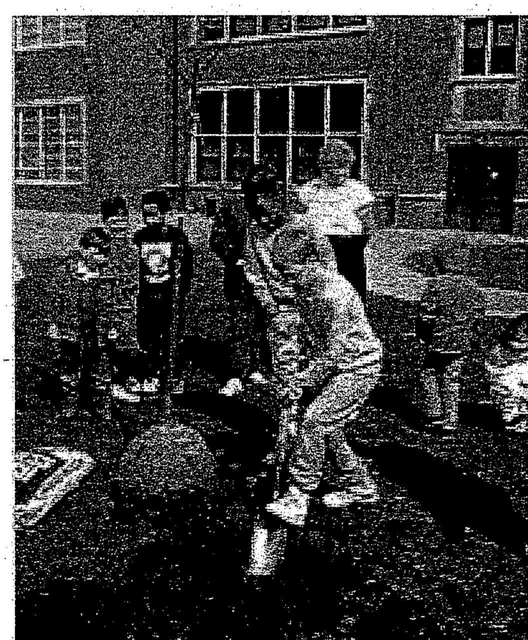


Photo: NRCS

Students at an elementary school in Des Moines, Iowa, plant a tree during Arbor Day celebrations.

6. Parking Policies to Reduce Number of Spaces Needed

Definition

Parking lots are one of the more visible aspects of imperviousness within the built landscape, and managing stormwater through better parking lot design is contained in many of EPA's guidance documents on improving water quality. Retrofitting parking lots is emerging as a popular BMP; however, an equally effective approach is to reduce the footprint associated with parking spaces before they are actually built. Thus a parking policy that updates land development standards and zoning codes to reduce the parking footprint is a BMP.

This subsection looks at two broad techniques for reducing the amount of imperviousness associated with parking:

Photo: www.pedbikeimages.org/Dan Burden

This streetscape design ties together retail activity, landscaping and parking. Tree grates were designed to capture water and provide shade while also providing easy access for pedestrians and motorists as they exit the parking area along the street.

- **Structured parking:** Instead of surface lots, parking can be provided in garages. The same number of spaces can thus be provided on considerably less land. While parking can also be provided below grade, for most areas this is prohibitively expensive. Therefore, this subsection will discuss items mainly related to structured parking.
- **Reductions in number of spaces:** Reducing the number of parking spaces involves two main techniques:
  1) Reduce parking requirements which mandate a certain amount of parking. These requirements often require too many spaces but can be retooled to reduce spaces, provide flexibility for TOD, or change from minimum to maximum ratios.
  2) Encourage shared parking, by which users of two nearby facilities can share the same parking spaces at different times. For example, a church, which generally needs parking on Sunday mornings could share parking spaces with a movie theater, which needs parking spaces in the evenings. Shared parking can also apply to better use of on-street parking spaces.

This section does not include information on retrofitting parking lots with infiltration strips and landscaping since the focus is on the sizing and footprints for parking. There are links in the "Resources" section to more information on using infiltration techniques on new and existing parking lots.

Who Do I Talk to About Parking Plans and Requirements?

In general, parking requirements are contained in land use and zoning documents, and are typically expressed as minimum numbers of spaces per unit of development. They may be in plans held in the department of public works or in the office of planning. On-street parking is typically governed within the local traffic engineering office or in the department of public works. There are various types of parking and policies related to parking as discussed below.

Parking Requirements: Most zoning codes have detailed specifications of parking requirements by use (e.g., a commercial district may specify four parking spaces per 1000 ft^2 of office space). A residential district may require two off-street spaces per unit. Within a district, there may be further parking specification by use; for example, for a church or for fast food restaurants. Localities enacting smart growth plans are changing their parking standards in recognition that fewer spaces are needed when there are transportation options and a mix of uses. They are also changing policies to permit more flexible programs. For example, some jurisdictions are beginning to use maximum parking requirements instead of minimums. Review the parking requirements in your zoning codes, within special use permits, and in parking guidelines and stormwater ordinances that may serve as a barrier to flexibility. For example, language might require a business to satisfy its parking requirements within 400 feet and reserve parking only for that business. This could prohibit shared parking, as discussed below.

Photo: EPA

Transforming parallel spaces to diagonal ones on this wide retail street increases the amount of parking without adding impervious surface.

Parking Overlay Districts: Overlay districts introduce new requirements. Parking overlays are good for transit districts, where policies are needed to support several modes of travel. For example, a TOD district may have a parking overlay that reduces the number of spaces needed based on proximity to a transit stop. Combining a parking overlay district with complimentary policies, such as shared parking agreements among several building owners, can help to balance demand for spaces throughout the day in a parking overlay district. In this case of TOD districts, you may need to also consult the transit agency.

On-Street Parking: One of the most overlooked resources for parking is one that already exists—use of the street. There are a variety of management techniques to help use this resource, such as meters, permit parking and angled parking. These spaces

Photo: City of Boulder, Colorado

In Boulder, Colorado, downtown developers are discouraged from building parking for individual projects. Instead, they pay a parking and transportation in-lieu fee. These fees are then used to build public garages, as well as to fund transit, bicycle, and pedestrian improvements.

can be governed by the Public Works departments, or by a special parking office.

Site Plan Conditions or Proffers: If your jurisdiction negotiates site-specific development requirements, check the office that oversees site plan conditions or proffers. Often the number and location of parking spaces is a negotiated element on a project-by-project basis.

Structured parking: Structured parking can either be a multi-level lot or underground parking. Because of the expense involved, structured parking typically occurs in downtown areas, districts with higher densities, or near arenas and stadiums.

Shared parking: Some shared parking plans may be drawn by local redevelopment organizations or business improvement districts, or by large institutions like universities or hospitals. In larger cities, private parking companies may also exist, so check with them as you gather information on opportunities to improve parking policies.

Parking Pricing: Parking pricing introduces a fee for parking. Pricing typically serves as a transportation demand strategy (to reduce vehicle use), a parking management strategy (to reduce problems in specific locations), and/or as a means to raise money for parking and other projects.

Determining how much parking to provide for retail, offices and residential areas is a balancing act to make sure there is enough parking to support the range of intended uses, but not so much as to undermine good community design and stormwater improvements. As shown in Table 3, the decision on how many spaces to provide is more often than not tilted toward an oversupply.

Stormwater Benefits

Reducing the amount of surface parking reduces the quantity, speed, and impurities of the runoff. For example, one researcher calculated that a one-inch rainstorm on a one-acre meadow would produce 218 cubic feet of runoff, while a parking lot the same size would produce 3,460 cubic feet.[21] Among the pollutants that accumulate on parking lots are cadmium, copper, lead, zinc, nickel, cobalt, and iron, which are found in gasoline, grease and oils, antifreeze, brake linings, and rubber.

Under most parking standards, the number of spaces required is often dictated by times of "peak use," such as holiday shopping, which tends to be heavier than at other times

Table 3: Conventional Minimum Parking Ratios

Land Use	Parking Requirement		Actual Average Parking Demand
	Parking Ratio	Typical Range	
Single family homes	2 spaces per dwelling unit	1.5 - 2.5	1.11 spaces per dwelling unit
Shopping center	5 spaces per 1000 ft^2 GFA	4.0 - 6.5	3.97 per 1000 ft^2 GFA
Convenience store	3.3 spaces per 1000 ft^2 GFA	2.0 - 10.0	—
Industrial	1 space per 1000 ft^2 GFA	0.5 - 2.0	1.48 per 1000 ft^2 GFA
Medical/dental office	5.7 spaces per 1000 ft^2 GFA	4.5 - 10.0	4.11 per 1000 ft^2 GFA
GFA: Gross floor area of a building without storage or utility spaces			

Source: *Parking Generation, 2nd edition*. Institute of Transportation Engineers, Washington, DC. 1987; Smith, Thomas. *Flexible Parking Requirements*. Planning Advisory Service Report No. 377. American Planning Association, Chicago, IL. 40 pp. 1984; Wells, Cedar. Impervious Surface Reduction Technical Study. Draft Report. City of Olympia Public Works Department. Washington Department of Ecology, Olympia, WA. 1994.

of year. By reducing the number of spaces and integrating flexibility to handle peaks, there can be an overall reduction in the amount of impervious surface.

In 1993, the city of Olympia, Washington, launched its impervious surface reduction study to simultaneously address water quality concerns and a growing population. As part of this larger study, the city conducted a comprehensive study of parking. The city found that, on average, 53 percent of commercial sites were taken up by parking lots. As part of the impervious surface reduction study, the researchers studied the feasibility of reducing commercial parking. They found that, while business owners did not think they provided too much parking, the typical occupancy rate in parking lots was only 46 to 67 percent. Eighteen of 31 representative sites had less than 75 percent occupancy rates during the busiest peak hours surveyed. The city also calculated that during a two-year rain event (2.8 inches in 24 hours), approximately 38 cubic feet of runoff would be generated by a 9-foot by 18.5-foot surface parking space (not including drive aisles and turn lanes).[22]

Typical Costs

Surface vs. structured parking: For a given parcel of land, structured parking is always more expensive than surface parking. According to one industry estimate, construction costs for parking spaces range from $1,500 to $1,800 per space for surface parking, and from $12,000 to $20,000 for structured parking (costs in 2000 dollars).[23]

Parking requirements: Although there is no hard cost to changing parking requirements, municipalities will need to devote staff time or resources to hire a consultant to write new

Photo: EPA

In Saint Louis, Missouri, rush hour lanes along a main arterial are converted to diagonal parking on Sunday for nearby churches. This system allows many more cars to use on-street parking for the limited hours on Sunday when demand for spaces is high and traffic volumes are less than that generated on weekdays during rush hour.

parking ordinances. If a locality wants to add more on-street metered parking, there are supply and administrative costs, though these can be offset by meter revenue. Note that some localities are using meter revenue to support the costs of planning and supporting parking for downtown and retail districts.

Shared parking: In situations that lend themselves to shared parking, there are two main costs to making it happen. First, the parties involved generally draw up an agreement, which may present costs in terms of researching what to include and legal fees. Second, ongoing maintenance costs must be divided. Providing on-street parking makes use of an asset that is technically paid for and shared, and thus adds no additional cost to the developer or user. In addition, supplying parking in a lot requires more impervious surface to provide drive aisles, entrances and ramps. On-street parking does not require this extra infrastructure, thus lowering the amount of land, and thus cost, to provide parking.

Measurable Goals

One quantifiable goal could be reducing the amount of parking in new developments or redevelopment projects; for example, reducing the percentage of surface parking in new developments' footprints by 5 percent. Another measurable goal could include changing ordinances to require maximum parking ratios instead of minimum ratios, adjusting downward the number of spaces used in a locality's standards for parking, and encouraging the use of shared parking.

Another measurable goal could be a surface lot replacement program. Where excess capacity is identified, the city can assess which lots are candidates for infill and which lots could be retrofitted with infiltration techniques. The decisions will likely be based on development trends, water quality goals and the availability of incentives. As with the discussion on infill and redevelopment, characterizing the performance should be conducted on a site, neighborhood, and watershed scale.

Examples

Surface vs. structured parking: Montgomery County, Maryland, contains four parking districts around rail stations. Special taxes are levied on development within the districts, and the zoning ordinance encourages structured parking by exempting parking garages from those taxes.

On-street Parking: In **Arlington County, Virginia**, the redevelopment plan for Columbia Pike places minimum requirements for providing public parking and maximums for the provision of private parking. A developer may pay an "in lieu of fee" if the parcel is too small to meet the standards. One innovative aspect of the plan is the ability to count adjacent on-street public spaces toward the parking requirement. The parking plan also includes a focus on centralized, shared parking that will create a "park once; then walk" environment for visitors who choose to drive.

Santa Rosa, California, is conducting a parking project in its downtown area with "back-in" diagonal parking. In the pilot phase, 22 spaces replaced 15 parallel on-street spaces. With these spaces, motorists traveling along a street would drive past a diagonal parking space and then back into it. This layout makes easing back into traffic safer, since the motorist can see oncoming traffic and bicyclists.

Parking requirements: A number of **California** jurisdictions have innovative parking requirements that effectively reduce the number of spaces required for residential development. For example, San Diego allows housing built in a transit-intensive area or designated for low-income residents to have 0.25 fewer spaces per unit. Sunnyvale allows 0.3 or 0.4 fewer spaces per unit if parking is unassigned (as opposed to available in private garages). Concord allows developers to request a variance from existing codes if housing will be occupied by seniors or disabled persons.

San Antonio, Texas, has both minimum and maximum parking requirements. For example, most retail uses must provide at least one space for each 300 square feet of gross floor area, but no more than one space per 200 square feet. In addition, structured parking and lots paved with pervious materials are exempted from maximums, providing an incentive for developers to reduce parking impacts.

The **University of Washington** has initiated a pay-per-use parking program that replaces monthly parking passes with a per-hour fee. University employees are electronically charged each time they park rather than paying a flat monthly fee. Users also receive a free bus pass and Flexcar membership.

Shared parking: The city of **Tualatin, Oregon**, granted a 25-percent reduction in parking spaces required by mixed-use development Tualatin Commons in return for shared parking.

Points to Consider

Once you have decided on new parking strategies like the ones outlined in this subsection, an important consideration is what to do with the land that is no longer dedicated to parking spaces. Water quality specialists might think the most obvious choice is to dedicate the land to absorbent open space. However, this open space may serve to scatter development and result in unwalkable "office parks." From a redevelopment position, the obvious answer might be to fill it up with development, though this action could eliminate options for handling more water on site. The answer will depend on your community's goals and site constraints.

Good urban planning will consider a compact form that addresses stormwater, a walkable and viable development program, and how people move in and around the site.

Surface vs. structured parking: Structured parking incentives can be coupled with parking regulations that allow a maximum parking footprint (or impervious area) per residential unit.

Parking requirements: Many neighborhoods oppose reducing parking requirements under the assumption that this will result in more commercial "spillover" parking in the neighborhoods. Some jurisdictions have adopted "zone" parking that only allows residents to park on streets in the affected neighborhood. These zones can be limited to rush hours or 24 hours if the neighborhoods are experiencing severe spillover pressure for parking. In addition, developers might wish to reduce the number of spaces they are required to supply, but feel pressure from their financial backers to oversupply parking. An ample supply of parking is often viewed as a necessity for financial success or the ability to sell the property in the future. As the Washington State study shows, this view may overlook the financial penalty that comes with building spaces that ultimately are rarely (or ever) used.

Shared parking: Although there are many potential instances in which shared parking can be used, there are several reasons why it is not as common as it might be. First, if the uses do not share a common property manager, they need formal or informal agreements to share parking. Second, they may not agree on whose responsibility it will be to maintain parking lots. Third, many business owners worry that their customers will stop patronizing them if they do not perceive that parking is adequate. Fourth, developers may fear that businesses will be less likely to lease their space or residents less likely to live there if they perceive the parking supply to be inadequate.

To overcome these problems, local jurisdictions can draw up shared parking guidelines to get the business community behind such plans. To see what a model shared parking agreement looks like, go to Metro-Portland's *Shared Parking Handbook* at <www.metro-region.org/article.cfm?articleid=435>.

Car sharing: Car sharing has emerged as a viable transportation option in many areas. Car sharing works best in urban environments that have a fairly high density of residential units (so that there are enough potential members to use the service) and other transportation options, such as transit and the ability to make pedestrian trips. Most of these cities were covered under Phase I of NPDES, but university towns developing plans and ordinances under Phase II might be good candidates for introducing a car sharing program. The Car Sharing Network publishes an updated list of all cities where car sharing is underway at <www.carsharing.net/where.html>.

The company Flexcar has studied the issue and estimates one shared car can take up to six cars off of the road (see <www.flexcar.com/vision/impact.asp>). The stormwater benefits are achieved when one car can be used to meet the needs of several drivers. These benefits include reduced demand for parking and car storage, as well as a reduction in automobile-related deposition on roads that can pollute runoff.

"Green Parking:" New technologies for pervious pavers and porous pavement are advancing rapidly. This technology is particularly attractive for low traffic areas and for spillover parking needed for athletic events, churches, fairs, and episodic activities. Replacing existing impervious cover for parking with pervious pavers has appeal and can provide water quality improvements where urban runoff is a main contributor to water quality problems. Replacing existing parking spaces with green technology and materials can help abate stormwater runoff and the pollutants carried in that runoff.

Green parking materials may not, however, lessen all of the environmental effects related to excess parking. Decisions on the total transportation system will be made to consider road design, number of turning lanes, drive aisles, and parking. In areas where your local transportation department is trying to balance transportation choices, the addition of new spaces, no matter the material, may work at cross purposes with smart growth plans aimed at making pedestrian trips as attractive as driving. In addition, green pavers require periodic maintenance. Fine debris and dirt accumulate in the drainage openings and reduce the pavement's flow capacity. It is natural for settling and clogging to occur over time, so maintenance schedules require vacuum sweeping several times per year.[24] When adopting policies for green pavement and materials, review the overall development design and transportation goals to find the right incentives or program for emerging technologies related to parking.

7. "Fix It First" Infrastructure Policies

Definition

"Fix It First" infrastructure policies place spending priorities on repair of existing infrastructure over installation of new infrastructure. Generally these refer to transportation infrastructure (e.g., roads, bridges, and rail systems) and water infrastructure (e.g., sewers and drinking water treatment/distribution), but may also apply to use of existing schools or other public buildings.

Who Do I Talk to About "Fix It First" Policies?

The first stop in any discussion about infrastructure is typically the public works department or city/county engineer, though your inquiries may be specific to a certain type of infrastructure.

Transportation: Your local public works department generally has a division devoted to streets, which would have information on projects underway or that are in the last stages of planning. The public works director or city/county manager might also know

Photo: Dan Burden

Reducing the amount of stormwater that enter curbs and gutters can be an effective means of lessening the effects of urban form on local waterways.

A008235

whether your locality has a framework for how transportation budgets are allocated for new construction and repair. On a regional level, the MPO or regional planning agency has knowledge of large-scale transportation planning and projects. MPOs are regional multi-jurisdictional organizations created for areas with a population greater than 50,000. They are mandated to make transportation spending decisions for metropolitan areas over 250,000 in population and would have information on any regional or state policies that prescribe funding priorities and allocation. At the state level, the department of transportation would have information on any such policies, though departments of community affairs or smart growth offices may have the most comprehensive information on statewide "Fix It First" policies.

Water: On a local level, the responsibility over water infrastructure (e.g., drinking water and sewer service) is typically shared by the local government and water utilities. New infrastructure, increases in capacity, and larger repairs are typically included in Capital Improvement budgets. Once installed, water utilities cover operation and maintenance for treatment plants and conveyance systems. Local and county governments often have the most control over the extension of water and sewer service into new development areas. These extensions can be governed by annexation rules, interlocal agreements among cities and counties, planning documents, or can be made on a case-by-case basis. You may need to talk to someone in the planning office to see how extensions and prioritization of repair decisions are governed.

Increasingly, infrastructure specific to handling stormwater is handled through a stormwater utility, though most funding lies within local capital improvement or operating budgets. Stormwater utilities are discussed in Subsection 9.

Because water infrastructure investments are large, funding might include state and federal money. How those funds are spent can rely on requirements established through a state revolving fund, a state capital improvement project or other programs. Thus, your local water infrastructure manager is likely to refer you to state offices and other Web sites. Further explanations may also be available through the city/county attorney, since the funding requirements are often established in regulations.

In some areas, large water projects may be planned and funded as part of large state and federal projects such as dams, canals and reservoirs. Though not a widespread practice, there are also some private water suppliers and engineering firms that could have control over capital and repair decisions.

Stormwater Benefits

"Fix It First" policies have long-term effects on stormwater management and can be a smart growth technique to encourage infill construction and redevelopment. In addition, "Fix It First" policies encourage replacement of older infrastructure, which can be a significant source of stormwater-related problems, particularly in older urban and suburban areas. In particular, sewer overflows during wet weather events can have severe environmental impacts. Inadequate or degraded systems can also increase the chances or severity of property damage from flooding.

"Fix It First" programs also can include new treatment technologies to improve the performance of existing systems. Many people are unaware that most stormwater runoff entering storm drains is not filtered and flows untreated into waterbodies. Oil/grit separators and in-pipe systems can be incorporated into the repair or routine maintenance of storm drains and pipes. For even stronger results, "Fix It First" policies can be coupled with techniques listed in Table 2 on page 23 to handle and filter as much stormwater as possible on individual properties.

Typical Costs

"Fix It First" policies are built on the assumption that funds for infrastructure are limited and thus rely on shifting spending rather than increasing available funds. The costs are therefore measured in both short-term and long-term impacts, since they shift spending from new infrastructure (new capital spending) to existing infrastructure (repair, operations, and maintenance).

Even in cases where cities are developing strong programs to attract redevelopment, the poor condition of pipes and water handling facilities can be a barrier. The cost to repair water infrastructure around the country has been the subject of discussion and review—in particular, the funding needs to replace aging infrastructure. EPA recently launched a Sustainable Water Infrastructure initiative to complement the traditional funding programs with management techniques to lower costs, add efficiencies to water distribution and treatment systems and

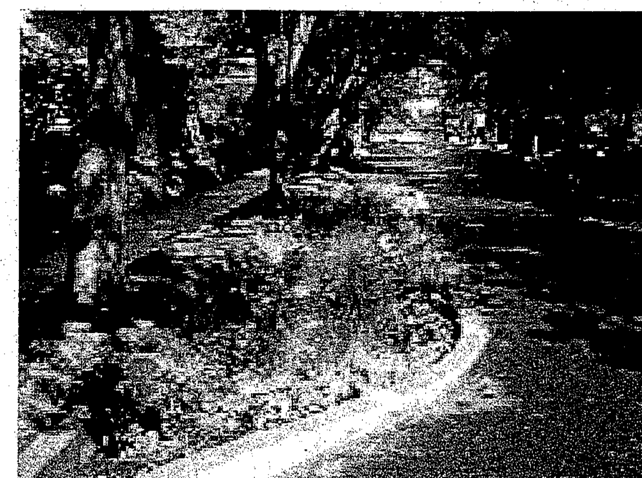


Photo: City of Portland, Bureau of Environmental Services

As part of Portland's "Green Streets Program," the city launched the Siskiyou project to add water-absorbing curb extensions. These vegetated extensions intercept some of the stormwater flow before it enters storm sewers. This type of feature can be added as part of a street repair program in older parts of town where a reduction in stormwater flow is needed.

use a watershed approach for managing water infrastructure. Localities that are developing or fine-tuning smart growth plans will recognize parallels in this sustainable approach. Common themes include efficient use of land and water resources, a focus on existing infrastructure and investments, and the use of a regional approach to manage resources. See <www.epa.gov/water/infrastructure>.

Measurable Goals

For a jurisdiction that has a "Fix It First" policy, a goal might be to rehabilitate 25 percent of existing water infrastructure, roads, and bridges over a five-year period. A locality could also express goals in terms of linear feet of pipes replaced. For a jurisdiction without such a program, the goal might be to adopt a "Fix It First" policy at the state level.

Examples

Beaufort County, North Carolina, is part of a multi-county program to reduce nitrogen and phosphorous loadings to the Tar and Pamlico Rivers. The county has submitted a stormwater management plan to the state to meet both state laws governing nutrient reductions and Phase II. Its August 2004 draft stormwater plan includes the opportunity to allow an exemption from nutrient reduction requirements for projects included in redevelopment areas with a "Fix It First" policy. For more information, see <h2o.enr.state.nc.us/nps/TarPamlico_Nutrient_Trading_Program_files/documents/BeaufortPgm8-13-04.doc>.

New Jersey passed legislation in 2000 requiring its Department of Transportation (NJDOT) to reduce the backlog of bridges and pavement needing repair by half over a five-year period. It also forbids construction of new road investments unless approved by a joint resolution of the state legislature. The NJDOT must report annually on its progress in achieving these and other goals. Michigan and Massachusetts have adopted "Fix It First" legislation over the past two years as well.

Sometimes "Fix It First" policies are not explicitly called such, but are embedded in other programs. Directing a percentage of funds to priority spending areas can turn out to be a "Fix It First" policy. Many water utilities also have CMOMs, or "Capacity, Management, Operations and Maintenance" plans. These plans are used to ensure efficient use of water and wastewater distribution systems to ensure adequate baseflow into streams, to avoid overflows, and allocate resources to strained lines and connections in the system. Utility mangers establish policies to direct funding. If you are a developer or work in an economic development department, contact your local utility to see if the budget policies are aligned with your city's redevelopment or economic development plan to direct development to existing activity centers.

Points to Consider

States like New Jersey are finding that smart growth policies to direct development and

Keep Water Out

Even if your storm sewers are not in need of repair, one way to stay off of the "Fix It First" list is to "keep water out." EPA is developing tools to help municipalities lessen the amount of stormwater that flows into combined and separate stormwater systems. The reduced volume of water has many advantages, including a reduction in the risk of overflows, less stress on pipes and conveyance systems, and lowered pollutant loadings.

Some of the management practices to reduce the amount of water flowing into storm sewers are the same as many practices listed in this publication, including the promotion of better site designs and reduction of impervious surfaces, such as lowering the parking standards in your municipality's codes. Portland, Oregon, is a leader in implementing both smart growth and water policies. The city has instituted, among other things, a downspout disconnection program, discounts on stormwater utility bills for homeowners who handle stormwater on site, and a pilot stormwater credit trading program.

Once your "Fix It First" program has completed the investment in new infrastructure, you can prolong the investment by reducing stormwater flows that enter your gray infrastructure.

redevelopment are complicated by the fact that workable infrastructure is sometimes not in place. This highlights the importance of having infrastructure in place as you implement plans for redevelopment and infill. Implementing a "Fix It First" policy before other policies are in place may help your community realize redevelopment on a more predictable track. Likewise, a strict "Fix It First" policy may have the unintended consequence of prohibiting development in "greenfields" that are desired growth areas. New Jersey recently included language in infrastructure grants to give priority to infrastructure funding in preferred growth areas. A successful joint policy may include the pairing of redevelopment and "Fix It First" programs in order to synchronize public and private smart growth investments.

The redrawing of funding allocations creates redistribution of existing funds (or has the appearance of doing so). Communities might find it helpful to consider the economic and environmental goals of infrastructure policy on a watershed wide basis.

Finally, much of the evolution in thinking on water and stormwater has turned to green infrastructure, or using natural systems to handle stormwater. Green infrastructure need not be isolated to rural or suburban areas, as pointed out in Subsection 5 (Tree and Canopy Programs). States and localities should recognize, however, that policies to prioritize green infrastructure should not come at the expense of fixing aging pipes in areas served by gray infrastructure. Communities may want to seek out where the green and gray infrastructure support each other, or better, where green infrastructure can alleviate stormwater flow into both combined and separated systems.

8. Smart Growth Street Designs

Definition

Smart growth street designs are based on a network of well-connected streets that support multiple modes of transportation. Some smart growth approaches to street design include multiple route choices, alternative street and sidewalk designs, adjusting the vehicular level of service (LOS) and/or creating LOS for other modes of transportation, and designing connected street networks and sidewalks to support multiple uses.

Increasingly, stormwater guidance manuals list "green" techniques to mitigate the runoff from existing streets or those in the preliminary design phase, such as swales and elimination of curbs and gutters. The main emphasis in this section is the underlying street patterns, the connecting of transportation networks and the retrofitting of existing streets for multiple uses. The "Resources" section lists green techniques for streets which may be used to complement your smart growth street plans.

Photo: Anacostia River Business Coalition, Washington, DC

Street and curb designs can be modified so stormwater flows into natural areas for treatment. Grates to handle overflow can reduce the chances of street flooding during heavy wet weather events.

Who Do I Talk to About Street Designs?

The rules that govern local street designs are most likely to be found at the local level in the public works department or in subdivision guidelines. Check with your department of transportation or planning to find out what policies are in place. In addition, individual developers may develop their own street networks for planned unit developments (PUDs).

For streets that are already in place, there may be opportunities to improve connectivity and make better use of the existing street right-of-way. These may be included in long range comprehensive plans or redevelopment plans. Some of the improvements were listed in the previous subsection on parking. Other plans for streets may also be housed in the department that governs environmental improvements.

Subdivision codes may also have requirements about street design. Where the codes are not explicit about street design, check to see if there are requirements regarding connections to surrounding parcels, streets, or developments. Some jurisdictions require multiple connections, while others may limit the number of connections. For example, a code may require no more than two connections from the subdivision.

State departments of transportation play a role in building or improving state-controlled roads. In many growing areas, smaller highways and rural state roads are the main thoroughfares identified to serve new housing and commercial growth.

Stormwater Benefits

Because streets constitute the largest share of impervious cover in residential developments (about 40 to 50 percent), a shift to narrower streets can result in a 5- to 20-percent overall reduction in impervious area for a typical residential subdivision.[25] As nearly all the pollutants deposited on street surfaces or trapped along curbs are delivered to the storm drain system during storm events, this reduced imperviousness translates into a lower volume of stormwater runoff and pollutant loadings from the development. For stormwater quality factors, residential streets rank as a major source for many pollutants, including sediment, bacteria, nutrients, hydrocarbons, and metals.[26]

Understanding how a connected street network works to control stormwater on a watershed basis requires a review of how roadway design has evolved. Beginning in the 1960s, typical roadway design practices favored a less networked, "hierarchical" street design. This design begins at the lot level, with numerous unconnected streets, in particular for residential areas. Aerial photographs of subdivisions reveal common unconnected layouts, such as "lollipop" designs with cul de sacs, or communities with only one entrance. Within housing subdivisions, the individual, smaller streets feed into collector roads, which then lead, often through only one intersection, to arterials. The arterials (which in some cases are highways) link large, centralized trip generators, such as shopping centers, office parks, and subdivisions. Because there are few alternative routes of travel, the road system is designed to handle the collective flow of travel through key intersections onto other large arterials. This road and intersection system features multiple turning lanes, wide intersections, and access lanes designed to minimize congestion with the collected and concentrated flow of traffic. This type of system increases the amount of land needed to handle collected traffic, concentrates traffic onto fewer roads, increases the pressure to widen the roads that handle collected traffic, and creates barriers to travel options, such as pedestrian trips.

Communities developing alternatives for multi-modal networks often turn to the 10 smart growth principles (see page 18) for guidance. The principles of creating walkable neighborhoods, mixing land uses, providing transportation options, directing development to existing communities and taking advantage of compact building design all come into play. The street systems that make this combination of features possible are characterized by multiple connections, as well as appropriately sized streets and intersections to support safe travel for vehicle drivers, bicyclists, and pedestrians. These street patterns can be in grids, but may also include paths and other connections. Although cul-de-sacs and dead-end streets are discouraged, there are a variety of street designs that can provide the slower traffic and privacy that homebuyers prefer, with the connections that help avoid the chokepoints and large feeder routes built into a hierarchical system. For stormwater engineers, the most beneficial point for a watershed lies in the compact form, which facilitates a higher intensity of development and mix of uses on less land.

The stormwater performance of smart growth street systems can be further enhanced by policies to reduce the amount of runoff entering the curbs and gutters, mentioned throughout this document. Likewise, developers and landscape architects can plan for intermittent retention areas to collect and treat some of the road runoff prior to discharge into a storm sewer system.

Finally, the notion of better stormwater management related to a tighter, connected network of streets with sidewalks may seem counterintuitive. Most literature on water quality highlights the detrimental effect of "connected impervious surfaces." Most efficient urban layouts are just that—highly connected streets and blocks. Thus, when making the case for the stormwater benefits of smart growth street designs, urban planning and water resource professionals should establish the framework for considering the site, neighborhood, and region simultaneously, in the same way that has been presented for development districts. For most regions, the question of growth—and underlying road design—is not whether there will be growth or no growth, but rather what the growth (and roadway system) will look like and where it is located.

Typical Costs

Cost estimates vary widely. When building new street networks, narrower streets may cost less to build than wider streets. Considering that the cost of paving a road averages $15 per square yard, shaving even 4 feet from existing street widths can yield cost savings of more than $35,000 per mile of residential street. In addition, because narrower streets produce less impervious cover and runoff than wider streets, additional savings can be realized in the reduced size and cost of downstream stormwater management facilities.[27]

The costs will not necessarily always be lower, because specialized features like sidewalks, curb and gutter, street tree areas, and pavers are often included in the overall street design. These amenities, however, carry benefits for stormwater, transportation and community design, so a raw assessment of costs per mile or per trip might not capture the full range of benefits.

Installation of stormwater-friendly streets can also involve additional costs over streets constructed according to standard practices. Portland, Oregon, estimated a higher cost due to planting and maintaining landscaped buffers.[28] Where permeable or porous pavement is used, the site preparation for water storage involves additional costs. The cost savings these techniques bring for handling stormwater from streets can be hidden, however, because the budget for transportation and stormwater can be in separate accounts in different departments' budgets. In deliberations over stormwater utility rates, Portland estimated that 70 percent of its runoff could be attributed to transportation-related surfaces.[29] City and county managers should look to see where the higher costs of better street design are offset by lower demands on stormwater infrastructure.

Measurable Goals

Appropriate measurable goals for street design modifications are emerging. Like earlier discussions on development districts, local build-out analyses can help compare a "business as usual" scenario of build-out with one that contains more compact villages or districts. The streets component may be included with estimates of parking lanes, turning lanes, and other impervious surface coverage associated with roads and streets.

Another measurable goal might be the reuse—or new uses—of existing streets. For example, adding bike lanes, adding on-street parking, or adding medians could be included in your stormwater management plan.

Examples

The Institute for Transportation Engineers has developed two recommended practice guidelines: *Traditional Neighborhood*

Sidewalks on One Side of the Street – or Both?

Some states and localities are recommending that sidewalks be limited to one side of the street to reduce impervious cover, however, most smart growth plans endorse a network of sidewalks. Which is correct?

The answer lies not so much in stormwater control as it does in transportation. If sidewalks are designed as a prominent feature for handling a variety of trips (e.g., commuting, shopping, school travel, and recreation) and providing connections throughout the neighborhood, then placing them on both sides makes sense. If your project or plan envisions only recreational trips, however, then sidewalks on one side of the road makes sense. If you choose to only place sidewalks on one side, review the plan to make sure that future plans for growth and a mix of uses are taken into consideration so that sidewalks might be added later to meet the demand for pedestrian trips.

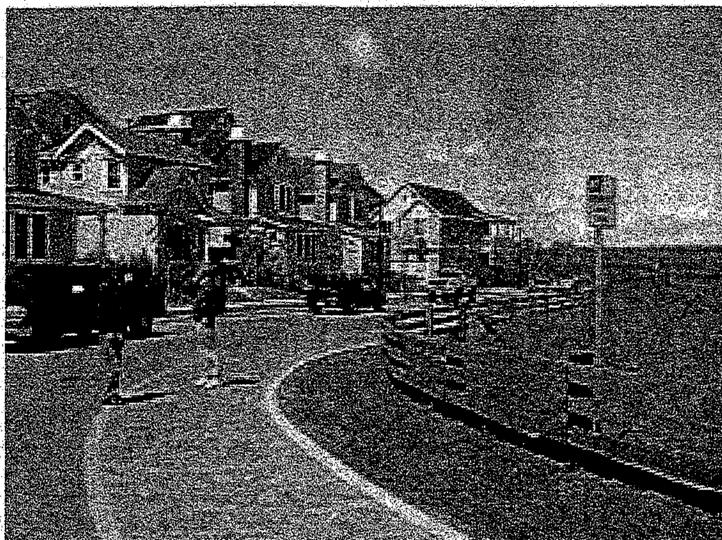


Photo: Local Government Commission

This street and sidewalk in Hercules, California, shows how multiple objectives can be met at once. The streets are narrow; however, the rounded curb allows extra width in case emergency response vehicles need extra room. The sidewalk is constructed of pavers, and slopes toward the grassy areas on the straightaway.

Development Street Design Guidelines (1999) and *Neighborhood Street Design Guidelines* (2003). These are available through ITE's bookstore at <www.ite.org>.

The metropolitan region around **Portland, Oregon** (Metro), has a regional street design manual, specifying stream treatments, street width, and associated water quality benefits. See <www.metro-region.org> and type "street design" into the site's search engine.

North Carolina's Department of Transportation (NCDOT) approved street design guidelines to make it easier for local governments to implement traditional neighborhood street networks in new developments. The guidelines specify street width and the provision of bicycle and pedestrian facilities. See <www.doh.dot.state.nc.us/operations/tnd.pdf> for more information and a link to the NCDOT *Traditional Neighborhood Development Guidelines*. The town of Cary, North Carolina, has adopted policies requiring street connections.

The Congress for New Urbanism (CNU), EPA, the Federal Highways Administration (FHWA) and the Institute of Transportation Engineers (ITE) are developing *Context Sensitive Solutions for the Design of Major Urban Thoroughfares*, which will provide alternatives for communities seeking smart growth street standards. Publication is expected in 2006. In the meantime, a literature review was developed in 2005 and is available at <cnu.org/pdf/lit_review_assigned.pdf>.

Dane County, **Wisconsin**, has established *Street Standards for its Traditional Neighborhood Design Ordinance*. See <www.co.dane.wi.us/plandev/build/pdf/tnd/20040225_append_C.pdf>.

Points to Consider

Street designs have traditionally been established through sets of commonly recognized standards. Standard-setting organizations, such as the Institute of Transportation Engineers and the American Association of

State Highway and Transportation Officials have issued standards that govern street designs, recommended road widths and design for turn lanes and access roads. These organizations are aware that the standards do not fit all situations, and are developing alternative standards and guidelines for communities that have smart growth plans. Because the alternative standards are new or in draft form, local transportation officials might be reluctant to adopt them. Stormwater and planning officials may want to meet with their transportation counterparts in developing a streets plan for joint stormwater and smart growth efforts.

Building green streets, narrower streets, and multi-purpose streets can cause citizen concern and raise objections from emergency service providers. In Portland, Oregon, engineers, planners, and emergency response providers made test runs of various street widths to come to a decision on a street width that meets both smart growth and emergency response needs. The Local Government Commission has developed fact sheets on designing multi-use streets, available at <www.lgc.org> (look under "Free Resources" for the fact sheets).

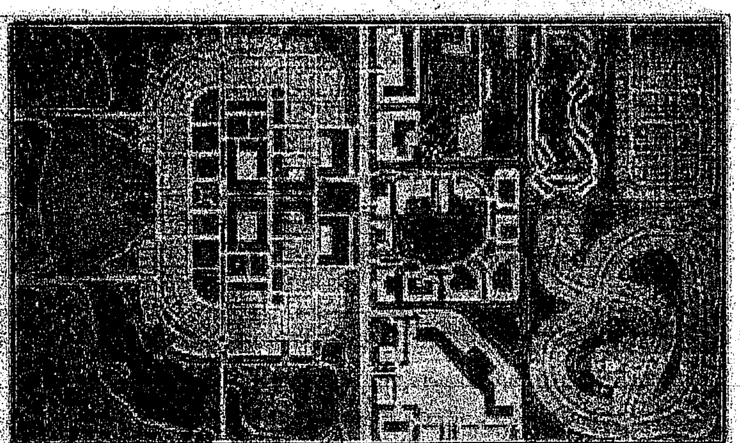


Image: Local Government Commission

This diagram compares a traditional street layout with the unconnected streets associated with conventional subdivisions.

As noted earlier, a denser network of narrower streets can involve as much or more impervious surface within a concentrated district. This is where evaluating imperviousness on a "per unit" basis of development is helpful. This might be per unit of housing, or per square foot of development footprint. In redeveloping districts, smart growth designs often call for the addition of streets to break up larger blocks or connect centers of activity and the addition of sidewalks to promote walking. While these measures add impervious surface coverage, evaluating the environmental performance of this design requires a broader approach, as mentioned above.

Finally, street design and construction is increasingly delegated to the developer and his or her site planners. For conventional residential or commercial development projects, the main requirements for connecting the development project deal with access to state highways or local roads. As noted above this access point is typically the only point of ingress and egress for the project. Local governments might experience resistance from developers who are not used to planning multiple connections to neighboring developments, or providing connections to commercial areas. Communities with smart growth street plans that require multiple connections will find that early and constant outreach is necessary so builders, developers, and land owners are aware of the requirements. In addition, local governments and real estate agents need to make potential homebuyers aware of streets that will be connected to future development projects to avoid conflicts.

9. Stormwater Utilities

Definition

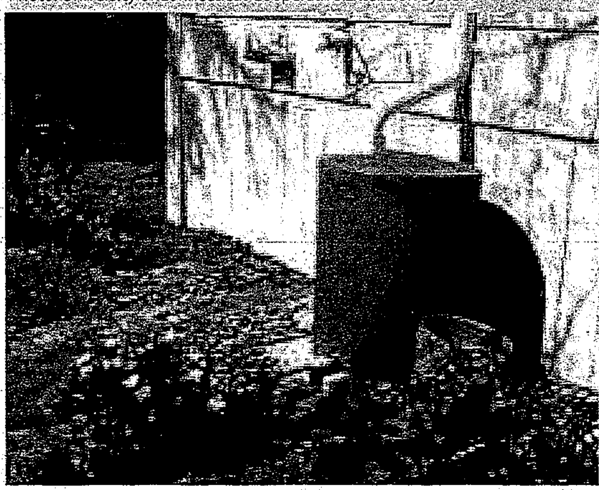
Like urban forestry programs, stormwater utilities are not typically listed as smart growth policies. Many states and localities, however, have investigated where the rate structure of other utility programs, such as electricity, cable, and gas service, might be unintentionally subsidizing new growth at the expense of more cost-efficient service areas. A stormwater utility, like other utilities, establishes an organization where a user pays for municipal services, such as water, trash pick-up and sewer. This subsection includes suggestions for communities that have already made the decision to establish a utility to finance stormwater improvements.

Stormwater regulations have spurred interest in stormwater utility creation as localities seek new ways to fund drainage and flooding projects. The legal structure and rate system for stormwater utilities vary around the country, and can depend on state legislative or enabling language. The legal aspects of establishing a stormwater utility are beyond the scope of this publication, but there are several things to look for in setting up a utility in coordination with smart growth goals. The mission statement, rate structure, and planning can all have influence over a locality's ability to shape a comprehensive approach to handling stormwater.

Who Do I Talk to About Stormwater Utilities?

Stormwater utilities are typically set up by a local government (as mentioned above, most states must first pass enabling legislation allowing localities to establish these utilities). Thus, the first step is to make sure that the legal framework exists for the creation of a utility. For ease of billing, stormwater utility fees typically appear on the same bill issued for water and sewer, so you might find contact information there or in your local government directory. The stormwater utility may also be located in the public works department. The local government will typically post information on how the stormwater utility is organized, the billing structure and the stormwater master plan on a Web site.

Photo: University of Connecticut Cooperative Extension System



Stormwater utility rates can be adjusted to add incentives for homeowners who collect and handle rainwater on their properties. Municipalities that have impaired waterways and are experiencing high rates of infill can use this approach to reduce stormwater volumes.

Of particular smart growth interest is the method of charging based on the percent of impervious surface coverage. A fee based on the percent of impervious surface coverage might not recognize the benefits of smaller lots in a compact district. Where densities are higher, the individual plots are likely to have a greater percent of impervious surface coverage. As explained in Subsections 3 (Redevelopment, page 48) and Subsection 4 (Development Districts, page 51), this design has a lowered impact overall when one considers the per unit impact in a watershed. A rate that recognizes the overall water benefits of higher density housing can help recognize the lowered impact on a per unit basis. An alternative to charges based on percent impervious surface is to develop a charge based for the development district which recognizes the lowered impact for the watershed. Fees can then be assessed per house within the district.

The redevelopment of older commercial corridors often begins with streetscape improvements, which can be designed to capture stormwater, provide tree canopy and complement the redevelopment goals of more walkable and economically vibrant districts.

Photo: NRCS

Commercial properties: Assessing rates for commercial properties is a bit more predictable and straightforward, but it is important to examine for any barriers to developement projects that have benefits for the watershed. Commercial properties are generally assessed a fee based on impervious surface coverage. One of the more important smart growth considerations is accounting for the stormwater impacts of redevelopment of vacant or underperforming commercial properties. As these parcels are redeveloped, they often generate the same amount of runoff as before, but as noted elsewhere in this report, they take on development demand that could go to undeveloped areas elsewhere in the watershed. To further improve the performance of these sites, look for opportunities to handle water on site or disconnect the impervious surfaces with neighboring parcels. In addition, a locality may want to introduce a stormwater fee credit for improving "gray" infrastructure, particularly when a developer agrees to fix combined sewer pipes that overflow. With these modifications in the rate structure, a property is fairly assessed its contribution to local impacts, but gets a credit based on the watershed benefits.

Depending on specific legal requirements, a utility may be able to split the rate into other types of categories to recognize smart growth benefits. This is where it is important, in the development of your utility's charter and planning, to develop a "purpose" statement to describe the adverse impacts of stormwater and establish a framework for recognizing better practices within the utility and its rate structure.

Summary and Conclusion

Cities, counties, towns and campuses around the country are well on their way developing stormwater plans under the Clean Water Act. What many local water quality managers might not realize is that their colleagues in the transportation and zoning departments are engaged in planning and development activities that parallel—and often overlap with—watershed and stormwater planning. Embedded in land use and comprehensive plans are features at the site, neighborhood, and even regional level that have a great impact on the quantity and quality of stormwater. Where the locality is pursuing smart growth development strategies and techniques, they are often unknowingly developing "best management practices" (BMPs) for Phases I and II.

This document was developed to help water quality practitioners, developers, smart growth advocates, and local/state government officials think in new ways about the overlapping demands of water planning and local comprehensive planning.

The Clean Water Act's stormwater permitting program offers opportunities to meet these overlapping demands. The water quality features of smart growth have not traditionally appeared in BMP menus or lists of stormwater performance measures. This document has taken common smart growth techniques, explained their water and stormwater benefits, and provided examples. Understanding the benefits, though, requires a new view of stormwater—one that considers multiple levels of environmental and development context. Thus, development projects must be evaluated at the site, neighborhood, and watershed levels to fully assess environmental performance.

In conclusion, the stormwater permitting program is designed to foster innovation and adaptive management. Over the next five years, your community is likely to observe opportunities for improvement. As your town engages in planning for transportation, regional planning, and development, pay attention to areas that are amenable to better water quality and stormwater management. You may find that you can gain water quality improvement while addressing transportation, housing, economic development, and community goals all in the same community.

Next Steps – Guidance and Technical Assistance for Municipalities

EPA also expects to improve its guidance and technical assistance on implementation of the NPDES stormwater permitting program for MS4s. For communities developing smart growth programs and stormwater management plans, the Agency is exploring activites that:

- Provide more information and assistance on watershed permitting for communities that want to integrate their smart growth plans.
- Support development of BMP manuals for common smart growth techniques and development districts, such as TNDs.
- Develop model codes, stormwater ordinances, and permit language that recognize the stormwater performance of smart growth and/or offer flexibility for redevelopment, infill, and smart growth site design for new development.
- Develop decision support tools to help localities and developers estimate the amount of stormwater pollution prevented through compact development and redevelopment.
- Develop information on strategic combinations of BMPs for urban infill and redevelopment that include smart growth and traditional stormwater BMPs.

EPA's Guidance on Post-Construction Stormwater Controls – Through a Smart Growth Lens

On December 8, 1999, EPA published the Phase II rules in the *Federal Register*, along with model language that could be adopted. EPA's language, presented below, was adopted in part or whole by many states and permitting authorities. The examples listed in the notice include a combination of traditional stormwater control techniques, as well as several smart growth techniques and concepts. If your state or locality has adopted some or all of the model language, here are some tips for integrating your existing smart growth plan with this guidance.

From the 1999 *Federal Register* Notice:

Post-construction storm water management in new development and redevelopment.

(i) You must develop, implement, and enforce a program to address stormwater runoff from new development and redevelopment projects that disturb greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale, that discharge into your small MS4. Your program must ensure that controls are in place that would prevent or minimize water quality impacts.

(ii) You must:

(A) Develop and implement strategies which include a combination of structural and/or non-structural best management practices (BMPs) appropriate for your community;

(B) Use an ordinance or other regulatory mechanism to address postconstruction runoff from new development and redevelopment projects to the extent allowable under state, tribal or local law; and

(C) Ensure adequate long-term operation and maintenance of BMPs.

(iii) Guidance: If water quality impacts are considered from the beginning stages of a project, new development and potentially redevelopment provide more opportunities for water quality protection. EPA recommends that the BMPs chosen: be appropriate for the local community; minimize water quality impacts; and attempt to maintain pre-development runoff conditions. In choosing appropriate BMPs, EPA encourages you to participate in locally based watershed planning efforts which attempt to involve a diverse group of stakeholders including interested citizens. When developing a program that is consistent with this measure's intent, EPA recommends that you adopt a planning process that identifies the municipality's program goals (e.g., minimize water quality impacts resulting from post-construction runoff from new development and redevelopment), implementation strategies (e.g., adopt a combination of structural and/or non-structural BMPs), operation and maintenance policies and procedures, and enforcement procedures. In developing your program, you should consider assessing existing ordinances, policies, programs, and studies that address stormwater runoff quality. In addition to assessing these existing documents and programs, you should provide opportunities to the public to participate in the development of the program. Non-structural BMPs are preventative actions that involve management and source controls such as: policies and ordinances that provide requirements and standards to direct growth to identified areas, protect sensitive areas such as wetlands and riparian areas, maintain and/or increase open space (including a dedicated funding source for open space acquisition), provide buffers along sensitive water bodies, minimize impervious surfaces, and minimize disturbance of soils and vegetation; policies or ordinances that encourage infill development in higher density urban areas, and areas with existing infrastructure; education programs for developers and the public about project designs that minimize water quality impacts; and measures such as minimization of percent impervious area after development and minimization of directly connected impervious areas. Structural BMPs include: storage practices such as wet ponds and extended-detention outlet structures; filtration practices such as grassed swales, sand filters and filter strips; and infiltration practices such as infiltration basins and infiltration trenches. EPA recommends that you ensure the appropriate implementation of the structural BMPs by considering some or all of the following: preconstruction review of BMP designs; inspections during construction to verify BMPs are built as designed; postconstruction inspection and maintenance of BMPs; and penalty provisions for the noncompliance with design, construction, or operation and maintenance. Stormwater technologies are constantly being improved, and EPA recommends that your requirements be responsive to these changes, developments, or improvements in control technologies. (Citation: 64 *FR* 68843, December 8, 1999).

For communities that have embarked on smart growth planning, there are several overlapping themes:

"EPA recommends that the BMPs chosen: be appropriate for the local community; minimize water quality impacts; and attempt to maintain pre-development runoff conditions."

Listing your smart growth accomplishments and their water quality impacts is one way that your BMPs can be appropriately chosen. As mentioned in this document, maintaining pre-development runoff conditions for redevelopment projects is typically neutral since impervious cover replaces existing impervious cover. In some areas, localities have defined pre-development conditions as the **undeveloped** state. There may be water quality imperatives that call for this increased standard. The key is to ensure that all development projects in the watershed are held to standards that lead to increased protection so that redevelopment rules do not unintentionally penalize redevelopment compared to new development.

"...implementation strategies (e.g., adopt a combination of structural and/or non-structural BMPs)..."

For smart growth and stormwater goals, the most effective BMPs will be strategic combinations of mutually supportive policies. For example, policies to create better sidewalks might lead to pedestrian improvements at intersections, which in turn are supported by plans for a more compact town center to bring uses within walking distance of each other. These policies act to support each other and are synergistic, so that the end result is the cumulative benefits of the individual policies. Many comprehensive plans recognize the combinations or urban design policies; make sure that your stormwater plan reflects the same links among policies.

"...Non-structural BMPs are preventative actions..."

Note that prevention of stormwater-related problems is integral to EPA's guidance. As noted in this document, reusing existing developed areas and compact building forms prevent much of the stormwater generated from development activity.

"...and measures such as minimization of percent impervious area after development..."

EPA's guidance does emphasize reducing impervious area. When considering reductions, however, the development context for smart growth and stormwater are important. While each individual property may meet impervious surface caps, the development "footprint" becomes enlarged as individual development sites grow to include the required land set-aside. This, in turn disperses uses and the infrastructure needed to serve it, including roads and other impervious surfaces. Thus, while the narrow objective of minimizing impervious surface coverage on the development site level is met, the watershed can actually see an increase in land disturbance and impervious surface coverage. Water quality practitioners should recognize that while land development approvals are made on a site-by-site basis, the impact of the individual development project transcends boundaries. This is not to say that impervious surface caps do not have a place in protecting water quality. In some places, watershed-wide caps have been put into place, followed by assessments of the land conservation/development balance. Like other aspects of development decisions, the scale, location, and interrelationship with other policies are important.

"...minimization of directly connected impervious areas..."

Communities that are seeking to add a street to connect an older downtown to new residential areas might find that strict policies to reduce connected, impervious surfaces prohibit the connections that are needed for economic development and transportation improvements. Screen your impervious surface policies to see where improvements to make compact development work might be prohibited.

"EPA recommends...preconstruction review of BMP designs."

Preconstruction reviews can identify where there is disagreement among details in various land development policies. The preconstruction review should include several departments to identify where a city or county's smart growth policies and stormwater regulations run counter to each other, and to develop alternative site designs to accomplish the goals of all programs.

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15 Khattak, Asad and Daniel Rodriguez. July 2005. Travel behavior in neo-traditional neighborhood developments: A case study in USA. Transportation Research Part A: Policy and Practice. Volume 39, Issue 6, Pages 481-500.

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SECTION 3

Resources

This section lists resources for general smart growth, for water resources by smart growth technique (as listed in the document for easy reference) and by state. A listing of these sites is not an EPA endorsement, and as materials are finalized and updated, links may change. Many stormwater programs at the state and local levels are being revised, so keep these keywords in mind if you need to use a search engine to find updated links:

"NPDES"

"Phase I" or "Phase II"

"MS4"

"stormwater"

"BMP"

"ordinance"

"design manual"

"post construction"

"redevelopment"

"infill"

These terms used singly or in various combinations, coupled with the name of your state and/or municipality, should take you to Web sites that contain information on the progress of stormwater programs, schedules for public meetings, drafts for review, opportunities for incorporation of smart growth techniques, and other information.

Many of these links cite regulatory documents, and thus are necessarily long; an electronic version can be found at <www.epa.gov/smartgrowth> to copy and paste Web addresses to your internet browser.

Smart Growth

For more information on making the integrated smart growth and water case, visit
www.epa.gov/smartgrowth or www.smartgrowth.org.

A good introductory primer is "Why Smart Growth: A Primer"
www.epa.gov/smartgrowth/pdf/WhySmartGrowth_bk.pdf

"Our Built and Natural Environments: A Technical Review of the Interactions between Land Use, Transportation and Environmental Quality"
www.epa.gov/smartgrowth/pdf/built.pdf

Planetizen, a planning and smart growth Web site, lists 50 good Web sites:
www.planetizen.com/websites

The Congress for New Urbanism has a compendium of model codes on a variety of subjects, including street design, rehabilitation, and urban design. The compendium also includes place-specific codes.
www.cnu.org/pdf/code_catalog_8-1-01.pdf

Water and Smart Growth

EPA has issued several helpful resources on growth and water resources:

"Protecting Water resources with Smart Growth"
www.epa.gov/smartgrowth/water_resource.htm

EPA's Watershed Academy hosts an online training course.
www.epa.gov/watertrain/smartgrowth

EPA's Region 6 has compiled an exhaustive list of water resources that are applicable throughout the country. The site also lists the Web sites of state stormwater offices for each of the 50 states and U.S. territories.
www.epa.gov/region6/water/npdes/sw/resources.pdf

The Met Council has released a series of documents on controlling stormwater in cold climates.
www.metrocouncil.org/environment/watershed/bmp/manual.htm

Stormwater Sites

EPA's main site for NPDES permits:
http://cfpub.epa.gov/npdes/index.cfm

EPA's stormwater program home page
http://cfpub.epa.gov/npdes/home.cfm?program_id=6

EPA Fact Sheet on Phase II
www.epa.gov/npdes/pubs/fact2-0.pdf

State stormwater programs
http://cfpub.epa.gov/npdes/linkresult.cfm?program_id=6&link_category=2&view=link

Resource List for Stormwater Management Programs and Phase II
www.epa.gov/npdes/pubs/sw_resource_list.pdf

Menu of Best Management Practices (BMPs)
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/menu.cfm

The Stormwater Authority lists state programs, news, white papers, and articles
www.stormwaterauthority.org/

The Natural Resources Defense Council's "Stormwater Strategies"
www.nrdc.org/water/pollution/storm/stoinx.asp

Project NEMO (Non-point Education for Municipal Officials)
http://nemo.uconn.edu

EPA's National Management Measures to Control NonPoint Source Pollution from Urban Areas
www.epa.gov/nps/urbanmm/

Innovations in Phase II Guidance and Permits to Include Smart Growth

EPA's model permit for Phase II includes language on specific smart growth techniques (e.g. infill), as well as flexibility to custom design ordinances and guidance.
www.epa.gov/npdes/pubs/modpermit.pdf

The Michigan Environmental Council is developing materials on smart growth and Michigan's innovative stormwater and watershed permitting.
www.michiganenvironmentalcouncil.org

The Santa Clara Valley Urban Runoff Pollution Prevention Program has developed a new Phase I permit to include many smart growth innovations. Under the reissued permit, the city of San Jose revised local ordinances to incentivize smart growth projects, such as affordable housing and redevelopment.

- The regional permit:
  www.scvurpppw2k.com/pdfs/other/NPDES_Permit_C3New_Finalodrtransltr.PDF
- The San Jose Policy changes:
  www.sanjoseca.gov/planning/stormwater/pol_stormwater.pdf

The city of Poway, California, has defined BMP to include redevelopment and development projects that improve stormwater performance as compared to conventional designs.
www.codepublishing.com/ca/poway/Poway16/Poway16101.html#16.101.200

Resources by Smart Growth Technique

Regional Planning

EPA's Surf Your Watershed
www.epa.gov/surf

EPA hosts a page on build-out tools
www.epa.gov/greenkit/2tools.htm

EPA link to source water protection plans
www.epa.gov/safewater/protect.html

The Trust for Public Land published "Protecting the Source" on regional source water protection efforts.
www.tpl.org
www.tpl.org/tier3_cd.cfm?content_item_id=1337&folder_id=195

New Jersey's program for regional and integrated planning
www.smartgrowthgateway.org

For information on the Highlands (New Jersey) water protection plan
www.highlands.state.nj.us/index.html and
www.state.nj.us/dep/highlands/faq_info.htm

New Jersey's Regional Plan Association hosts research and position papers.
www.planningpartners.org

RPA developed a paper on goal oriented zoning using smart growth techniques.
www.planningpartners.org/projects/wma11/sg_alt/smartgrowthalt_text.pdf

The Association of New Jersey Environmental Commissions' Smart Growth Survival Kit
www.anjec.org

The Central New York Regional Planning Board's regional assistance program for Phase II communities
www.cnyrpdb.org/stormwater-phase2/

The University of Rhode Island's Cooperative Extension's A Creative Combination: Merging Alternative Wastewater Treatment with Smart Growth
http://www.uri.edu/ce/wq/mtp/PDFs/manuals/Creative%20Combination%203-10.pdf

The Planning Commissioners Journal hosts a page on transfer of development rights programs, including examples, common challenges, and resources.
www.plannersweb.com/wfiles/w370.html

Appalachian Regional Commission's site on strategic planning and best practices.
www.arc.gov/index.do?nodeId=44

Infill

The Washington State Phase II permit application
www.ecy.wa.gov/programs/wq/stormwater/phase_2/Phase%20II%20Application.pdf (see page 14 for the language on infill development).

The Greenbelt Alliance published "Smart Infill" with information on zoning codes, design, and public participation
www.greenbelt.org (go to "Resource Center" and "Reports")

The Metro Council published the Urban Small Sites Best Management Practice (BMP) Manual.
www.metrocouncil.org/environment/Watershed/bmp/manual.htm

Association of Metropolitan Planning Organizations
www.ampo.org

The Local Government Commission, the REALTORS, and EPA co-published "Creating Great Neighborhoods: Density in Your Community"
www.lgc.org/freepub/PDF/Land_Use/reports/density_manual.pdf

Smart Growth America produced "Choosing Our Community's Future" to assist neighborhood leaders in shaping growth in their neighborhoods.
www.smartgrowthamerica.org

Wisconsin developed post-construction standards that vary for development type (i.e., new development, redevelopment, infill).
www.dnr.state.wi.us/org/water/wm/nps/stormwater/post-constr/

Clark County's (Washington) comprehensive plan
www.co.clark.wa.us/longrangeplan/review/index.html

Wisconsin Department of Natural Resources' list of general land use terms
dnr.wi.gov/org/es/science/landuse/education/GPZ.htm.

New Jersey's two-tiered permit system for infiltration requirements
www.njstormwater.org

Austin, Texas, smart growth incentives for infill
www.ci.austin.tx.us/smartgrowth/incentives.htm

San Diego's Localized Equivalent Area Drainage program (LEAD) for sharing stormwater costs across projects
www.sannet.gov/stormwater

The Center for Watershed Protection sponsors Builders for the Bay, "Smart Site," and the Site Design Roundtable
www.cwp.org

Maryland's Guide to BMP Selection
www.mde.state.md.us/assets/document/chapter4.pdf

Redevelopment

The National Vacant Properties Campaign has information on the most common conditions leading to vacated properties, and ways to develop programs that can bring unproductive property back.
www.vacantproperties.org/

The Congress for the New Urbanism's Greyfields into Goldfields
www.cnu.org/cnu_reports/Executive_summary.pdf

The U.S. Department of Housing and Urban Development's Smart Codes in Your Community: A Guide to Building Rehabilitation Codes
http://www.huduser.org/publications/destech/smartcodes.html

The Smart Growth Leadership Institute has a Web site devoted to code audits to identify barriers to redevelopment.
www.sgli.org/implementation.html

The U.S. Green Building Council's (USGBC's) scorecards, called LEED (for Leadership in Environmental and Energy Design), contain rating systems for development and redevelopment projects. USGBC has a new scorecard under development call LEED Neighborhood Design (LEED ND).
www.usgbc.org/leed/leed_main.asp

EPA's case study of the Atlantic Steel redevelopment project
www.epa.gov/projectxl/atlantic/index.htm

Development Districts

The state of Oregon created a design manual for development districts, which can serve as a base example for developing a joint smart growth and stormwater design manual.
egov.oregon.gov/LCD/docs/publications/wqgbchapter4dsnstan.PDF

Emeryville, California, developed design guidelines for highly urbanized areas with limited opportunities for infiltration – Design Guidelines for Green, Dense Redevelopment. The final document will be released in 2006.
www.ci.emeryville.ca.us/planning

Elm Grove, Wisconsin, has developed plans to include downtown revitalization, stormwater control, and open space planning.
www.elmgrovewi.org

Chesterfield, Burlington County, in New Jersey has a code for transfer of development rights, including a "Planned Village Development" district ordinance for receiving areas.
www.smartgrowthgateway.org/ordinances/chesterfield.pdf

EPA Brownfields site
www.epa.gov/swerosps/bf/index.html

San Diego's "City of Villages" planning initiative
www.sandiego.gov/cityofvillages

San Diego's Urban Runoff Program
www.sandiego.gov/stormwater

The Trust for Historic Preservation sponsors the Main Street Program
www.mainstreet.org/

Caltrans has a site dedicated to transit oriented development. This site describes each project, giving information on land use plans, transportation performance, and project details.
transitorienteddevelopment.dot.ca.gov

The Congress for New Urbanism's compilation of code innovations
www.cnu.org/pdf/code_catalog_8-1-01.pdf.

New Urban News developed New Urbanism: Comprehensive Report & Best Practices Guide, which contains analyses, best practices, and examples. To order, go to
www.newurbannews.com.

Tree Programs

Treelink has a page with links to tree preservation, urban forestry, and urban design ordinances.
www.treelink.org/linx/?navSubCatRef=25

Casey Trees is developing detailed information on the amount of stormwater that can be intercepted by tree cover and green roofs.
www.greenroofs.org/resources/greenroofvisionfordc.pdf

American Forests has information on research, ordinances, and CITYGreen software.
www.americanforests.org

International Society of Arboriculture
www.isa-arbor.com

Scenic America has a model tree ordinance and supporting information
www.scenic.org/portals/0/trees%20-%20ordinance.doc

Trees Atlanta's assessment of the benefits of tree canopy
www.treesatlanta.org

The USDA Forest Service Southern Region
www.urbanforestrysouth.org

Metro's Trees for Green Streets: An Illustrated Guide
www.metro-region.org/article.cfm?articleid=263

Parking Reduction Strategies

Parking Spaces/Community Spaces is set for release in 2006 from EPA.
www.epa.gov/smartgrowth.

The Stormwater Center has a fact sheet on planning, designing and retrofitting parking lots.
www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/GreenParking.htm

Olympia, Washington's Impervious Surface Reduction Study
depts.washington.edu/cwws/Research/Reports/ipds.pdf

Model agreement for shared parking
www.metro-region.org/article.cfm?articleid=435

The North Central Texas Council of Governments developed guidance, which includes parking reduction strategies.
www.dfwstormwater.com/Storm_Water_BMPs/post-construct.asp#rec

Information on car-sharing
www.carsharing.net/where.html

"Fix It First"

The National Governors Association issued an Issue Brief on "Fix it First."
www.nga.org/cda/files/0408FIXINGFIRST.pdf

EPA's Sustainable Water
www.epa.gov/water/infrastructure.

Smart Growth Street Design

The Institute for Transportation Engineers developed two recommended practice guidelines: "Traditional Neighborhood Development Street Design Guidelines" (1999) and "Neighborhood Street Design Guidelines" (2003).
www.ite.org

The Victoria Transport Policy Institute hosts an online transportation encyclopedia. This frequently updated site includes many details on transportation and street networks and includes examples from across the country, as well as international examples.
www.vtpi.org/tdm/index.php

The American Planning Association has issued a report, Planning for Connectivity: Getting from Here to There, Report PAS #515, written by Susan Handy, Robert Paterson, and Kentt Butler.
www.planning.org.

The metropolitan region around Portland, Oregon (Metro) developed a regional street design manual, specifying stream treatments, street width, and associated water quality benefits.
www.metro-region.org (type "street design" into the site's search engine)

North Carolina's Department of Transportation (NCDOT) approved street design guidelines for Traditional Neighborhood Development Design.
www.doh.dot.state.nc.us/operations/tnd.pdf

The Local Government Commission developed fact sheets on designing multi-use streets.
www.lgc.org (under "Free Resources")

The Congress for New Urbanism published a literature review of street designs for traditional neighborhood design and smart growth projects. This literature review will be used to support further work with the Institute of Transportation Engineers on the subject.
cnu.org/pdf/lit_review_assigned.pdf

Dane County, Wisconsin, adopted traditional street standards.
www.co.dane.wi.us/plandev/build/pdf/tnd/20040225_append_C.pdf

Seattle launched the Siskiyou Green Street Project to add vegetated curb extensions. These extensions handle some of the stormwater that would otherwise enter the storm sewer.
www.portlandonline.com/bes/index.cfm?c=dhfjc

Stormwater Utilities

The Center for Urban Policy and the Environment at Indiana University-Purdue University Indianapolis (IUPUI), in cooperation with EPA, hosts a page dedicated to stormwater finance. Some of the case studies provide examples on how to creatively match the rate structure with impacts.

http://stormwaterfinance.urbancenter.iupui.edu/

Lake County (Ohio) Credit Manual for Tier 2 Cities, Lake County Stormwater Management Department.

www2.lakecountyohio.org/smd/Credit%20Manual%20Level%202%20%20Advisory%20Board%20Approved.pdf

SECTION 4

New Jersey – A Case Study in Weaving Stormwater and Smart Growth Policies Together

The state of New Jersey has one of the most fully developed smart growth programs of any state. In 1985, the state adopted the State Planning Act, which led to the creation of a State Development and Redevelopment Plan (the State Plan). This plan was created through a statewide planning process called cross-acceptance, which ensures that governments at all levels, as well as stakeholders and the public, participate in deciding the future of New Jersey's growth. Early accomplishments included farmland protection, a land acquisition program, and comprehensive brownfields redevelopment policies.

In the early 1980s New Jersey passed its stormwater management rules. As attention to smart growth and the awareness of the environmental impacts of development increased, so did interest in updating stormwater rules. In the 1990s, with the new Phase II requirements on the horizon, the state developed rules with both growth and stormwater goals in mind. In 2003, the state passed two companion laws, one called the "MS4 Law" to establish a statewide permitting system, and the other called the "Stormwater Management Rule," which modernized the state's original stormwater laws and forged closer links between stormwater and other growth management plans.

Goals for Smart Growth

The purpose of the State Plan is to coordinate planning activities and establish statewide planning objectives in the following areas: land use, housing, economic development, transportation, natural resource conservation, agriculture and farmland retention, recreation, urban and suburban redevelopment, historic preservation, public facilities and services, and intergovernmental coordination

New Jersey uses the goals in the State Plan as a guide. The state is divided into five regions, with different goals based on the existing development profile, as well as plans for growth in that area. The accompanying State Plan Policy Map serves as the underlying land use-planning and management framework that directs funding, infrastructure improvements, and preservation for programs throughout New Jersey.

Goals for Water and Stormwater

The new stormwater rules are meant to complement other environmental and economic goals. The new rules place an emphasis on ground water recharge, though that requirement would be waived for urban areas. In urbanizing areas, LID techniques are to be used to maintain existing vegetation and drainage patterns. In all areas of the state, BMPs would be chosen to achieve an 80 percent reduction in certain pollutant loads. Areas along waterways designated as Category One (C1) water resources have special protections, such as the Highlands area of the state.

Specific Policies that Meet Both Water and Smart Growth Goals

This section describes policy areas that have both water and smart growth goals.

Tiered Stormwater Requirements:

Instead of creating blanket requirements for all areas of the state, New Jersey adopted two tiers to administer stormwater requirements. Municipalities within the state are assigned to either Tier A or Tier B. Tier A municipalities are generally located within the more densely populated regions of the state or along the coast. Tier B municipalities are generally more rural and in non-coastal regions. The Tier B Permit includes basic requirements and concentrates on new development and redevelopment projects and public education. The Tier A Permit includes the requirements found in the Tier B Permit, plus BMPs aimed at controlling stormwater pollutants from existing development.

Meeting Smart Growth Goals: By establishing tiers instead of general requirements, the state recognizes that the requirements based on development context can help create a level playing field so that greenfields development is not unintentionally favored due to less strict requirements.

Meeting Stormwater Goals: Tier A rules address stormwater problems found in urbanized areas, such as pet waste and litter. The infiltration requirements are tied to areas of the state critical for recharge, but are not required in urbanized areas where legacy pollutants may enter underground water systems.

"Fix It First:"

The New Jersey State Development and Redevelopment Plan and Infrastructure Needs Assessment, both adopted in March 2001, are used to encourage smart infrastructure investments. The "Fix It First" rules are particularly strong for transportation investments. For water and sewer infrastructure, the rules are not as explicit, but there are other policies that help direct funds for repair and replacements of water infrastructure. The State Planning Act links the state's annual capital budget recommendations to the State Development and Redevelopment Plan, and makes the Infrastructure Needs Assessment an integral part of the State Plan.

One concern voiced by developers is the poor condition of infrastructure in many of the designated growth areas. The state has responded through its "Water Quality Management Planning and Smart Growth Implementation Process" grant.

Meeting Smart Growth Goals: By focusing infrastructure investments in existing cities, towns, and suburbs, New Jersey can encourage downtown revitalization, decrease development pressures on farmland and other open space, and conserve limited funds by taking advantage of past infrastructure investments.

Meeting Stormwater Goals: Combined sewer overflows account for much of the pollution in New Jersey's waterways and harbors. Fixing aging infrastructure can mitigate —or eliminate—this source of pollution. Over a third of Newark's 170-mile collection system is brick. Fixing the infrastructure not only helps with overflows, but also decreases the strain on the system caused by inflow and infiltration (I/I). In addition, upgrades to infrastructure in designated growth areas can attract development that may go elsewhere in sensitive watersheds.

Utility Policies:

The New Jersey Board of Public Utilities (NJBPU) is the state's utility regulatory authority with oversight over the state's energy, telecommunications, water/wastewater, and cable television industries. Following the creation of a board-wide Smart Growth Policy Team, the NJBPU looked at its infrastructure extension formula and the extent to which developers will be required to pay for the necessary infrastructure. The formula was established to accommodate growth based on where development is occurring and how infrastructure improvements can best be financed to support increased development in designated growth areas. As stated in the 2005 strategic plan, NJBPU wants to make developers constructing on greenfield sites bear the full cost of gas, electric, and water line extensions, while reimbursing older communities and designated growth areas for laying utilities on their own.

Meeting Smart Growth Goals: Currently, builders negotiate the amount they contribute to gas, electrical, and water line extension on a case-by-case basis often with large reimbursements, while the total cost of service expansion to new subdivisions is subsidized by ratepayers in cities and older suburbs. Adjusting the formulae for rates and extensions to reflect actual costs brings transparency to the costs of various development patterns. Denser, older communities are more efficiently served per unit that dispersed development, thus holding down both installation and long term maintenance costs.

Meeting Stormwater Goals: The BPU's adjustments to extension and rate policies complement "Fix It First" policies and those geared to directing growth to designated growth areas. Funds can be targeted to repair, replacement, and capacity upgrades rather than installation to serve new, dispersed development. Holding down utility costs in urban areas can attract residents and commercial entities.

Infill and Redevelopment Districts:

New Jersey has several programs and policies geared toward redevelopment and revitalizing existing neighborhoods. The list is long, and the accompanying policies, grant programs and incentives are too long to list here. Among the programs are:

- New Jersey's Office of Brownfield Reuse www.state.nj.us/dep/srp/brownfields/obr/

- Rehabilitation Subcode
  www.nj.gov/dca/codes/rehab/index.shtml
- Transit Village Initiative
  www.state.nj.us/transportation/community/village

Meeting Smart Growth Goals: The recycling of brownfields and vacant sites allows the state to meet its smart growth goals of protecting open space by clustering development on existing sites, already served by infrastructure. In addition, the state has taken strides to provide affordable housing and save historic buildings through redevelopment. The transit villages and older areas that are served by multiple modes of transit offers options and reduces the amount of infrastructure needed to support automobile dependent types of development.

Meeting Stormwater Goals: Both public and private sector investment in older areas provides funding for infrastructure upgrades. The focus on larger sites (brownfields, transit station areas) allows localities to better plan for handling stormwater on site.

Agricultural Smart Growth Plan:

New Jersey's 2003 Agricultural Smart Growth Plan provides a roadmap for the future of agriculture across the state. The plan consists of five components: 1) farmland preservation, 2) innovative conservation planning, 3) economic development, 4) natural resource conservation, and 5) agricultural industry sustainability. Other components of the plan aim to preserve 20,000 acres of farmland per year through 2009 and integrate economic development and smart growth into the agricultural industry. The future of agriculture in an expanding, global market also depends upon innovative planning techniques, economic development, natural resource conservation, and programs and policies which keep the industry viable. For more information visit <www.nj.gov/agriculture/smartgrowthplan.pdf>.

Meeting Smart Growth Goals: The Agricultural Smart Growth Plan primarily strives to achieve the goal of preserving farmland, but the plan also involves community and stakeholder participation in the decisionmaking process and encourages a sense of place in rural communities by strengthening their economies.

Meeting Stormwater Goals: The Agricultural Smart Growth Plan brings innovative conservation goals to protect stream buffers and target land best suited for infiltration and forestry. In addition the agricultural smart growth plan provides better tools to design commercial and residential growth. Targeting commercial entities to existing downtowns and encouraging rural housing development designs can help minimize the development footprint overall.

Transfer of Development Rights:

The transfer of development rights (TDR) is a tool used to encourage a shift in growth away from agricultural, environmentally sensitive, or historic open space to designated areas where new development is desired. By incorporating TDR provisions in their land-use regulations, municipalities can encourage the protection of open space at a far lower cost than outright purchase. In a TDR program, a community identifies a conservation area within its boundaries where it would like to see protected from development (the sending zone) and another area where the community desires more growth (the receiving zone) as identified in the municipality's land-use plan. Landowners in the sending zone are allocated a number of development credits, which can be sold to developers, speculators, or the community itself. In return for selling his or her development credits, the landowner in the sending zone agrees to place a permanent conservation easement on his or her land. Meanwhile, the purchaser of the development credits can apply them to develop at a higher density than otherwise allowed on property under the base zoning.

On March 29, 2004, then-Governor McGreevey signed a bill authorizing all municipalities in New Jersey to adopt TDR programs, making New Jersey the first state in the nation to make TDR available statewide. TDRs typically work best when they are used in combination with other policies. Receiving areas must be ready to accept the density being sent, which means the zoning and infrastructure must be in place.

Meeting Smart Growth Goals: New Jersey's TDR program meets several of the state's smart growth principles, most notably the protection of open space, farmland, and scenic resources; compact, clustered community design; and locating future growth in communities with existing infrastructure. The state has a well-developed program in the Pinelands. To see more on the details of how the TDR program has been established, see <www.nj.gov/dca/osg/resources/tdr/index.shtml>.

Meeting Stormwater Goals: Much of the land identified as sending areas are also critical for water and recharge. That water would become urban runoff if developed under conventional standards and would result in stream degradation throughout larger segments. Receiving areas, which can then be developed more intensively, can accommodate more development on a smaller footprint, thus making more efficient use of land on a per unit basis. While most TDR programs are geared toward farmland preservation, they can also be designed for erosion control and water quality. For example, a TDR program can be implemented along with a source water protection plan.

Acronyms & Glossary

Acronyms

BID—Business Improvement District

BMP—Best Management Practices

COG—Council of Governments

CWA—Clean Water Act

CZMA—Coastal Zone Management Act

ICMA—International City/County Managers Association

LID—Low Impact Development

LOS—Level of Service

MPO—Metropolitan Planning Organization

NACO—National Association of Counties

NAHB—National Association of Homebuilders

NPDES—National Pollutant Discharge Elimination System

NPS—Nonpoint Source Pollution

NRCS—Natural Resource Conservation Services

PFA—Priority Funding Area

SWMP—Stormwater Management Plan

SWPP—Stormwater Prevention Plan or Stormwater Pollution Prevention Plan

TIF—Tax Increment Financing

TDR—Transfer of Development Rights

TMDL—Total Maximum Daily Load

TND—Traditional Neighborhood Development

TOD—Transit Oriented Development

UDO—Unified Development Ordinance

USEPA—United States Environmental Protection Agency

Glossary

BMPs (Best Management Practices): Methods that have been determined to be the most effective, practical means of preventing or reducing pollution from non-point sources, such as pollutants carried by urban runoff. These methods can be structural (e.g., devices, ponds) or non-structural (e.g., policies to reduce imperviousness). BMPs classified as "non-structural" are those that rely predominantly on behavioral changes rather than construction in order to be effective. "Structural" BMPs are engineered or constructed to prevent or manage stormwater.

Biofiltration: The use of vegetation such as grasses and wetland plants to filter and treat stormwater runoff as it is conveyed through an open channel or swale.

Buffer Zone: A designed transitional area around a stream lake or wetland left in a natural, usually vegetated, state so as to protect the waterbed from runoff-related pollution. Development is typically prohibited or restricted in a buffer zone.

Charrette: A French word meaning "cart"; often used to describe the final, intense work effort expended by art and architecture students to meet a project deadline. In modern terms, a charrette is an intense community workshop, typically held over several consecutive days, conducted to gather ideas and develop feasible community design options.

Combined Sewer Overflows (CSOs) and Sanitary Sewer Overflow (SSOs): Overflows occur when pipes carrying sewage and/or stormwater are overwhelmed by a high volume of water, typically during rainstorms. Older cities tend to have combined sewers (stormwater and sewage are carried in the same pipe); however, sanitary sewers can overflow as well.

Detention: The storage and slow release of stormwater following a precipitation event by means of an excavated pond, enclosed depression, or tank. Detention is used both for pollutant removal, stormwater storage, and peak flow attenuation.

Exfiltration: The downward flow of water into the soil.

Floodplain: A natural or statistically derived area adjacent to a stream or river where water overflows its banks at some frequency during extreme weather events.

General Permit: A permit issued under the NPDES program to cover a certain class or category of stormwater discharges. These permits reduce the administrative burden of permitting stormwater discharges. Most permitting authorities also allow for individual permits, which are tailored to meet unique needs.

Hydrology: The science dealing with the properties, distribution, and circulation of water on and below the Earth's surface and in the atmosphere.

Impervious Surface: A hard surface area that either prevents or retards the entry of water into the soil mantle as occurs under natural conditions (prior to development), and from which water runs off at an increased rate of flow or in increased volumes. Common impervious surfaces include but are not limited to rooftops, walkways, patios, driveways, parking lots, compacted soil, and roadways. "Effective impervious surface" is commonly used to describe impervious surfaces connected to receiving water directly or with a conveyance device (e.g., curbs, pipes, gutters).

Infiltration: The process or rate at which water percolates from the land surface into the ground. Infiltration is also a general category of BMPs designed to collect runoff and allow it to flow through the ground for treatment.

Infiltration/Inflow (I/I): Clean storm and/or groundwater that enters the sewer system through cracked pipes, leaky manholes, or improperly connected storm drains, down spouts and sump pumps. Most inflow comes from stormwater and most infiltration comes from groundwater. I/I affects the size of conveyance and treatment systems and, ultimately, the rate businesses and residents pay to operate and maintain them.

Maximum Extent Practicable (MEP): A standard that applies to all MS4 operators under NPDES permits. The standard has no exact definition, as it was intended to be flexible to allow operators to tailor their stormwater programs to their particular site

MS4 (Municipal Separate Storm Sewer System): A publicly owned conveyance or system of conveyances that discharges to waters of the United States or waters of the state, and is designed or used for collecting or conveying storm water. Conveyances can include any pipe; ditch or gully; or system of pipes, ditches, or gullies, that is owned or operated by a governmental entity and used for collecting and conveying storm water. For purposes of implementing NPDES, regulated communities have been divided into small, medium and large MS4s:

- **Large MS4**: all municipal separate storm sewers that are located in an incorporated place with a population of 250,000 or more according to the latest Census.
- **Medium MS4**: all municipal separate storm sewers that are located in an incorporated place with a population of more than 100,000 but less than 250,000.
- **Small MS4**: any municipal separate storm sewer that is not defined as being "large" or "medium," but which meets certain criteria on density or other factors used locally for designation.

National Pollutant Discharge Elimination System (NPDES): A provision of the Clean Water Act that prohibits the discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state (where designated), a tribal government or Indian reservation.

Nonpoint source (NPS) pollution: Pollution that is caused by or attributable to diffuse sources. Typically, NPS pollution results from land runoff, precipitation, atmospheric deposition, or percolation.

Notice of Intent (NOI): An application to notify the permitting authority of a facility's intention to be covered by a general permit; exempts a facility from having to submit an individual or group application.

Permitting Authority: The NPDES-authorized state agency or EPA regional office that administers the NPDES program, issuing permits, providing compliance assistance, conducting inspections, and enforcing the program.

Pollution-generating pervious surfaces: A non-impervious surface with vegetative ground cover subject to use of pesticides and fertilizers. Such surfaces include, but are not limited to, the lawn and landscaped areas of residential or commercial sites, golf courses, parks, and sports fields.

Post-Construction BMPs: A subset of BMPs including source control and structural treatment BMPs that detain, retain, filter, or educate to prevent the release of pollutants to surface waters during the final functional life of development.

Retention: The process of collecting and holding surface and stormwater runoff with no surface outflow.

Runoff: Any drainage that leaves an area as surface flow.

Sanitary Sewer: An underground pipe system that carries sanitary waste and other wastewater to a treatment plant

Stormwater Sewer System: A system of pipes and channels that carry stormwater runoff from surfaces of building, paved surfaces, and the land to discharge areas

Stormwater Management: The prevention, control, and mitigation of the effects of stormwater runoff. Management programs include regulatory and non-regulatory aspects, but are typically integrated with other water quality programs.

Stormwater Management Plan (SWMP): A plan, which may be integrated with other land development plans or regulations, that spells out how a regulated entity intends to prevent and treat stormwater runoff.

Stormwater Pollution Prevention Plan (SWPPP): A plan to describe a process though which a facility thoroughly evaluates potential pollutant sources at a site and selects and implements appropriate measures designed to prevent or control the discharge of pollutants in stormwater runoff.

Total Maximum Daily Load (TMDL): A regulatory limit of the greatest amount of pollutants that can be released into a body of water without adversely affecting water quality.

Water Quality Standards: State-adopted and EPA-approved ambient standards for waterbodies. The standards cover the use of the waterbody and the water quality criteria that must be met to protect the designated use or uses.

Watershed: A geographic area in which water flowing across the surface will drain into a certain stream or river and flow out of the area via that stream or river. All of the land that drains to a particular body of water.

EPA

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Environmental Protection Agency
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GREEN TECHNOLOGY: THE DELAWARE URBAN RUNOFF MANAGEMENT APPROACH

A TECHNICAL MANUAL FOR DESIGNING NONSTRUCTURAL BMPs TO MINIMIZE STORMWATER IMPACTS FROM LAND DEVELOPMENT

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Integrated Land Management, Inc.

Prepared For

Delaware Department Of Natural Resources
And Environmental Control
Division Of Soil And Water Conservation

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CHAPTER 1 GREEN TECHNOLOGY OVERVIEW

1.1 BACKGROUND

By early 1970, the deleterious effects of urban runoff on stream water quality had become apparent (Coughlin and Hammer, 1973, and sources cited therein). At the time though, relatively few studies had focused on the nature, extent, and effects of urban runoff. Following passage of the Clean Water Act in 1972, Section 208 Reports from the states began to accumulate a considerable body of information. By the late 1970s, these reports had indicated that urban runoff is a significant source of Nonpoint Source (NPS) Pollution. However, it was difficult to determine the particular effects of urban runoff on water quality due to interferences from other pollutant sources (USEPA, 1984). To address the issue more thoroughly, the Nationwide Urban Runoff Program (NURP) in the early 1980s monitored urban runoff from 28 sites with a wide variety of land uses (USEPA, 1984).

Urban runoff has been known as a source of pollution of water bodies (Hartigan and others, 1979; USEPA, 1984). Urban and suburban regions contribute higher (NPP) loadings on a per acre basis than rural watersheds (CPB 1990). While urban runoff itself may have significant levels of pollutants, the way it travels to receiving waters from developed areas may have even greater implications. After traveling over impervious surfaces coated with fine sediments and their associated nutrients, metals and hydrocarbons, most runoff enters streams directly through piped conveyance systems. These connected impervious areas are referred to as Effective Impervious Areas (EIA). Pollutant loads from EIA surfaces are much higher than those from isolated impervious areas filtered by overland flow at a much slower rate. Instead of percolating into the soil, precipitation from EIA surfaces is diverted to runoff that quickly flows into the aquatic ecosystem (WDE, 1992).

Urban runoff impairs stream systems through two major processes: changes in the water chemistry and changes in stream hydrology. Studies show that urban stream pollution may substantially impair the viability of benthic macroinvertebrates. Urban runoff also fundamentally affects hydrology by increasing storm runoff while reducing recharge, and thus lowering base flow. As a result, stream banks erode on a regular basis, filling the streams with sediment and smothering organisms. The organisms remaining are further stressed by runoff pollutants, as well as by the low flows and elevated temperatures resulting from reduced recharge. Under these circumstances, runoff pollutant concentrations and available dissolved oxygen often approach toxic levels. As a result of these processes, streams in urbanized watersheds have been greatly impaired due to runoff from upland impervious areas. Changes in hydrology seem to be the more pernicious, and harder to rectify.

The issue of stream bank erosion is particularly important. A growing body of research indicates that increased frequency of bankfull flooding due to development is the dominant process that impairs urban streams. In areas where streambanks comprise erosive alluvial soils typical of floodplains, the increase in the frequency and duration of bankfull flow from urban runoff rapidly degrades stream banks. Instream bank erosion may be a dominant source of total suspended solids (TSS) in urban streams.

The threshold at which streams begin to show signs of impairment is surprisingly low, beginning at roughly 5% EIA, typical of low-density residential development. In areas of higher density development, streams may be heavily impaired, with the native community almost entirely replaced by more opportunistic species. The fish community thus shifts from game fish to rough fish. In heavily urbanized streams, worms may be the only organisms surviving.

The lakes and inland bays into which streams and rivers discharge are also adversely affected by urban runoff. In these slow moving or still waters exposed to full sun, excess nutrients cause algae to proliferate inordinately, resulting in eutrophication. In freshwater streams, ponds, and upper tidal rivers, excess phosphorus is the most damaging nutrient. In the lower tidal rivers and inland bays, excess nitrogen is the most damaging nutrient.

Recent research indicates that the current paradigm in stormwater management regulations requiring structural Best Management Practices (BMPs) such as wet ponds does not do enough to alleviate this impairment and, in certain cases, may actually exacerbate aspects of urban runoff. In response, the Green Technology approach has been formulated to mitigate the effects of development on stream ecosystems through the use of innovative nonstructural BMPs. The goal is not only to maintain the health of existing streams, but also to build a foundation for efforts to restore impaired streams.

This Technical Manual reviews current understanding of the impacts of urban runoff upon stream ecosystems and their associated riparian zones. This manual then presents how Green Technology BMPs can effectively address these impacts, and then how to properly design the most appropriate BMP. The technical approach set forth in this Manual is supported by a spreadsheet model and Users Manual in Appendix A to assist in the design of Green Technology BMPs. BMP Design standards, specifications and details are presented in Appendix B.

1.2 THE GREEN TECHNOLOGY BMP APPROACH

In the Green Technology approach, centralized treatment and/or storage facilities located at the "end of pipe" discharge from developed sites are classified as structural BMPs. While structural BMPs such as stormwater ponds and wetlands can be effective in controlling peak flows from the site, current regulatory requirements for these structures do not address the frequent storms that erode stream banks, and do little or nothing to promote recharge. Furthermore, structural BMPs can contribute to downstream flooding when discharges from separate on-site structural BMPs overlap. Structural BMPs can be effective in pollutant removal; but since they generally omit recharge, consume space, and require extensive maintenance, they are less appropriate for the task. There is an emerging recognition that wet detention structural BMPs contribute to elevated stream temperatures, and discharge algae laden effluent, which can substantially degrade the benthic community in the receiving stream.

As a result, many progressive agencies are promoting the Green Technology approach, which is designed to intercept runoff from rooftops, parking lots and roads as close as possible to its source, and direct it into vegetative recharge/filtration facilities incorporated into the overall site design and runoff conveyance system. Green Technology BMPs defined in this Manual include conservation site design, impervious area disconnection, conveyance of runoff through swales and biofiltration swales, filtration through filter strips, terraces, bioretention facilities, and recharge through infiltration facilities. These BMPs form the basis of Green Technology at the site engineering level.

As vegetated structures that do not rely on detention, these BMPs are "Green". However, while Green Technology BMPs may seem less complex than structural detention BMPs, procedures for their proper design require the same hydrologic and hydraulic methods used in designing structural BMPs. The Green Technology approach also includes a quantitative approach for estimating pollutant loads, and projecting how well a particular design will remove such pollutants. Hence it is a "Technology", capable of providing realistic estimates of pollutant loading and removal, while also addressing hydrologic and hydraulic parameters involved in urban site design. The detailed design principles set forth in this Manual are incorporated into a spreadsheet program, the "Delaware Urban Runoff Management Model", or DURMM.

1.3 GREEN TECHNOLOGY BMPs

The BMPs addressed in Green Technology and pertinent aspects of their design and performance are briefly summarized below:

Conservation Site Design - Site design standards to reduce the extent of impervious surfaces and increase the extent of wooded areas are a key element of this approach, as expressed in the "Conservation Design Manual for Stormwater Management" by DNREC and the Brandywine Conservancy (1997). This Conservation Design Manual addresses many of the background issues in urban runoff and discusses conservation design methods in detail. The reader is referred to it for greater details in Conservation Design principles. Green Technology provides a quantitative approach to define the benefits of Conservation Design.

Source Area Disconnection – Disconnection is the process of directing runoff from impervious surfaces over adjacent vegetated surfaces, providing infiltration and pollutant removal. Green Technology quantifies the runoff reductions by disconnecting flow from impervious surfaces as it discharges onto adjacent pervious areas.

Filter Strips – Filter strips spread runoff uniformly over a filtering surface of vegetation, providing infiltration and pollutant removal. Filter strips can provide substantial treatment if not overloaded by sediment and runoff. Green Technology quantifies the runoff reductions and pollutant removal of filter strips.

Biofiltration Swales/Grassed Swales - Biofiltration swales convey runoff at shallow flow depths through wide swales. They can be very effective in removing Total Suspended Solids (TSS) and adsorbed metals, although less effective in terms of nutrients. While swales are not thought to be capable of quantity management, designs incorporating check dams can provide substantial attenuation of peak flows. Green Technology quantifies the runoff reductions and pollutant removal of overland conveyance through properly designed swales.

Terraces - Terraces are swales extending across gentle slopes designed to intercept runoff and increase the potential for infiltration. In terms of pollutant removal, terraces operate as filter strips, as runoff flows into them from upslope. They are similar to swales in terms of runoff response. Green Technology quantifies the runoff reductions and pollutant removal of overland conveyance through properly designed terraces.

Bioretention Structures - These are landscaped pocket depressions designed to infiltrate runoff through an engineered soil media. Incorporated into the urban landscape, they can provide substantial filtering and nutrient transformations before runoff is discharged into the conveyance system. Ongoing research suggests that this BMP can be designed to provide substantial soluble phosphorus removal capabilities, unlike most other BMPs. Green Technology quantifies the runoff reductions and pollutant removal of overland conveyance through properly designed bioretention structures.

Infiltration Practices - Most Green Technology BMPs incorporate infiltration as part of the treatment process. Specific infiltration facilities include infiltration trenches. Infiltration trenches located in swales provide additional wetted surface area and storage volume, and often they can be designed to penetrate shallow impermeable soil profiles to recharge deeper soil horizons. Green Technology quantifies the runoff reductions of infiltration trenches.

Complementing these engineered BMPs, Riparian Buffer Systems (RBS) and Stream Bank Restoration (SBR) BMPs are other important Green Technology systems that can enhance receiving waters. These BMPs provide substantial improvements in stream habitat and stability, as well as reducing pollutants from urban runoff. RBSs provide considerable benefits to streams through shading, bank stabilization and litterfall. RBSs can also provide substantial runoff filtering and pollutant removal when conditions are favorable. Since RBSs are sensitive to concentrated flows, design procedures to ensure sheet flow through level spreaders, filter strips and parallel swales can be incorporated into the design of this BMP. A companion document specifically focused on RBS design is being prepared by DNREC.

Stream Bank Restoration differs from other BMPs in that it provides no direct hydrological controls, nor does it remove pollutants from upland runoff. However, by stabilizing eroding stream banks, it may be the most effective mitigation measure for unstable streams stressed by urban runoff. Technical approaches for design of SBR BMPs are not included in this Manual. Designers should review the available literature about SBR design.

1.4 MANUAL SUMMARY

Unfortunately, while there is great interest in using Green Technology BMPs, there are remarkably few rigorous procedures available for the engineering and regulatory community to utilize in designing them and evaluating their effectiveness. Many regulatory programs use a straightforward runoff volume approach, in which the increase in small storm runoff volume due to land development is to be treated and/or retained on site. However, this approach typically assumes a constant runoff volume in proportion to rainfall amount, and does not route runoff through nonstructural BMPs. Instead, simplified volume/outflow equations are extracted from the literature, without addressing the processes involved during storm events. Where this approach leads to over-design, it may be beneficial if the original reduction targets are inadequate, otherwise it causes unnecessary expense. Where it leads to under-design, the hydrological impacts are not adequately mitigated.

DNREC has created DURMM to provide a more rigorous hydrological design tool for Green Technology BMPs. A spreadsheet program is provided that incorporates modified TR-20 storm hydrology to project the hydrological response from contributing source areas. It segregates directly connected runoff from that which flows overland. It provides routines that account for the reductions in peak flow due to overland conveyance. It also includes simplified estimates of the storage volume required for detention in different nonstructural BMPs.

The process of BMP design involves a spreadsheet file for each source subarea and its array of BMPs. Discrete combinations of hydrological soil group and land cover are averaged to generate composite Curve Numbers (*CN*) for the pervious and impervious portions of each source area. Natural areas are treated separately. Impervious areas are also calculated separately, and routed according to the extent of their linkage with adjacent pervious surfaces. The resulting runoff parameters from the source area worksheet are imported into the BMP hydraulic design worksheet. The worksheet routes the source area runoff volumes and peak flows through the BMP based upon the input parameters.

Pollutant loading is calculated by applying typical event mean concentrations (EMCs) to the runoff volume allocated to each type of pervious and impervious surface. By segregating subarea loads according to the type and extent of land cover, the discrete source area approach used in the hydrologic calculations refines accuracy in estimating total pollutant loads. Pollutant removal by the BMP is based upon physical parameters such as slope, pretreatment volume, hydraulic residence time, surface/volume ratio, filter media type, and underlying infiltration characteristics. Given these factors, pollutant load reduction is calculated by algorithms relating input concentrations and decay transformations to estimate mass removal for each pollutant of concern.

The reported pollutant removal effectiveness of BMPs can be highly variable. However, by incorporating hydrologic and hydraulic parameters in runoff routing, and addressing the various removal processes as discrete algorithms within a BMP, better estimates of removal rates are possible. Some variability in projected removal rates is acceptable in any event, since hydrological changes are recognized as perhaps the primary impact of runoff. Furthermore, polluted runoff from the most frequent storms that causes the greatest stress can often be eliminated by the infiltration components of nonstructural BMPs.

DURMM not only provides the tools necessary for designing Green Technology BMPs, typical details of these BMPs in AutoCAD™ format are provided for use by the engineering community. Procedures for site analysis are provided, particularly as they relate to disconnection of impervious runoff. Given a thorough site analysis, locations where BMPs are most needed become apparent. As a Windows™ interface, data from AutoCAD™ or similar design programs can easily be imported into DURMM during project design. The particulars involved in the design of each type of BMP are readily accessible during this process so that calculation of source area impacts and BMP performance becomes an integrated procedure, and the BMP is designed as a fundamental part of the entire project design process.

To properly address the issue of urban runoff and best mitigate its impacts through Green Technology BMPs, it is first necessary to thoroughly examine the underlying issues. Chapter 2 summarizes the literature on urban runoff impacts, Chapter 3 summarizes the literature on pollutant loads, and Chapter 4 addresses urban runoff criteria. Details of the hydrology of urban runoff are set forth in Chapter 5, and runoff hydraulics and DURMM routing are discussed in Chapter 6. Chapter 7 summarizes pollutant removal processes, while the Green Technology BMPs are described in Chapters 8 though 11.

CHAPTER 2 URBAN RUNOFF IMPACTS

2.1 INTRODUCTION

There are considerable numbers of studies that relate the presence of uncontrolled urban runoff to impairment of streams throughout the US. Studies have demonstrated impacts upon the habitat and native stream ecosystems in the Puget Sound area (WDE, 1992; Horner and others, 1996; Booth and Jackson, 1997), the Midwest (Richards and Host, 1994; Dreher, 1997), and the mid-Atlantic (Coughlin and Hammer, 1973; Schueler and Claytor, 1996; Kennen, 1999; Maxted and Shaver, 1997, Jones and others, 1996).

Urban runoff can affect streams through two processes: its pollutants either stress or totally alter the native benthic community, thus eliminating game fish; and its modification of stream hydrology can result in substantial loss of habitat. Urban runoff can also affect lakes and estuaries by increasing nutrient loads, leading to eutrophication. Consequences include red tides, loss of fisheries, and waters too foul for recreation. USEPA (1999) provides an excellent review of the impacts of urban runoff on receiving streams. The following sections address these processes in detail to better define the problem, its causes, and how nonstructural BMPs can be better designed to mitigate impacts of urban runoff.

2.2 IMPACTS OF URBAN RUNOFF TOXICITY ON BENTHIC COMMUNITIES

Toxic compounds in urban runoff can substantially impair the viability of benthic macroinvertebrates. While these bottom-dwelling insects, worms, and crustaceans may not be directly important to human uses (except fly fishermen), they are a robust indicator of overall stream health. Where a healthy benthic community has shifted to a few pollution-tolerant taxa, a diverse fish assemblage including game fish disappears, to be replaced by a few species of rough fish, if any. Therefore, the Index of Biotic Integrity (IBI) used to evaluate fish assemblages are very closely related to indices of benthic community health. As it is much easier to obtain quantitative information on benthic communities, methods to determine benthic indices such as the USEPA Rapid Bioassessment Protocol (RBP) are almost universally used by the states to evaluate the extent of stream impairment in their 305 (b) Reports to Congress.

Since water chemistry is inextricably linked with the hydrology of urban runoff, it is difficult to segregate the relative influence of hydrological and chemical impacts. However, several studies have explored the impacts of exposure to urban runoff using methods that minimize hydrologic variables. While no study has conclusively demonstrated the toxicity of urban runoff to sensitive benthic taxa, several studies examine the effects of urban runoff toxicity upon test organisms, using the Whole Effluent Toxicity (WET) protocols requiring a 48 hour exposure for acute tests, and a longer exposure for chronic tests.

Urban runoff contains a wide variety of toxic compounds and metals. From a commercial site in the Lincoln Creek watershed, a heavily urbanized stream in Wisconsin, lead EMCs exceeded USEPA's acute toxicity standard in 90% of runoff events (WDNR, 1989, as cited in Bannerman, 2000). In the Dallas area, zinc was found in 100% of all sites, with median concentration in residential sites of 65 μg/l, and 130 μg/l in commercial sites. The acute water quality criterion of 112 μg/l was exceeded in 36% of the samples (Waller and others, 1997).

In California, concentrations of copper, lead, cadmium and zinc in urban runoff sediments are from 10 to 50 times the background levels found in sediments originating from open areas. Copper exceeded the acute objectives in 70% of observations, and zinc 61% of the time. However, soluble copper, which is considered the toxic species, exceeded the chronic objective only 5% of the time (Cooke and others, 1997). Chronic exposures to runoff from a heavy industrial site in California were lethal to *C. dubia* in 100% of observations, while runoff from residential and commercial sites was lethal 50% of the time, and moderately to highly toxic for the balance. Toxicity in the receiving Coyote Creek varied from event to event, ranging from no observed effect in most cases, to high levels of mortality (Cooke and others, 1997).

Accumulation of metals in the sediments has been recognized as potentially hazardous (Hartigan and others, 1979), and repeated resuspension of contaminated sediments during frequent storms may pose the greatest long term toxic impacts to fisheries (USEPA, 1984, Myers and others, 1985; WDE, 1992). For this reason, Livingston and others (1995) consider sediment sampling a better measure of potential urban runoff toxicity than water chemistry. Resuspension of copper from sediments during stormflow below an abandoned factory has been implicated as a cause of significant mortality to benthic organisms (Diamond, 1996). Locally, the Red Clay Creek in the Piedmont is a good example of the adverse effects of industrial discharges upon stream sediments.

Insecticides are another major toxic contaminant in urban runoff. Used extensively in residential settings, excess diazinon in effluent from many STPs in the southern USA has been implicated in their failure to meet discharge limitations. In Wisconsin, diazinon was reported in 20% to 49% of all samples, with a mean EMC of 0.11 μg/l (Bannerman and others, 1996). In the Dallas area, Waller and others (1995) report that diazinon was found in 100% of commercial and residential sites, and 83% of industrial sites. Median concentration in residential sites was 0.55 μg/l, with 20 of 31 observations in excess of 0.35 μg/l. For the water flea *C. dubia*, this is one value reported for the concentration at which 50% die (LC50). The LC50 of diazinon for *C. dubia* has been reported as high as 0.9 μg/l (Fernandez-Casalderry and others, 1994), so fewer events would exceed this LC50. Thus it is not surprising that acute WET tests of urban runoff from these sites showed minimal toxicity to *C. dubia*, even though most exceeded the acute criteria for zinc as well (Waller and others, 1995). In December, 2000, the USEPA passed rules to phase out the use of diazinon, so this insecticide should become less of a problem as its use declines.

The time scale of exposure is a particularly important issue. Herricks and others (1995) note that the exposure period for acute and chronic exposure in WET tests does not account for the time scale involved in streams, where chronic exposure lasts for the lifetime of the organisms. Herricks and Milne (1996) also noted that mortality from an acute exposure was not manifest until a chronic time period had elapsed. Nonetheless, Herricks and others (1997) reported mortality of *C. dubia* from exposure to the first flush of runoff from Lincoln Creek in WET tests. However, field tests of caged rotifers (*H. azteca*) and native isopods (*Asellus* sp.) showed no event-related effects on mortality.

To isolate flow effects, Crunkilton and others (1997) used mesocosms (essentially aquariums) of test organisms filled with circulating stream water. They reported that 93% of the tests showed significant mortality in *C. dubia* after a 14 day exposure to runoff in Lincoln Creek, and 100% of the tests showed significant mortality in the minnow *P. promelas* after a 61 day exposure. Growth rates of *P. promelas* during long exposures were also reduced relative to controls. Much less effect was seen in shorter duration exposures, supporting the results of Herricks and others (1997). They also note that more sensitive criteria such as biomass accumulation may be better suited to examine the effects of runoff toxicity.

Even more noteworthy, there was little difference in mortality between runoff and baseflow inputs to the mesocosms. This suggests that sediments may accumulate toxic pollutants from runoff events, and supposedly "clean" baseflow becomes toxic as it upwells through bottom sediments and absorbs pollutants.

Bioassay exposure to polyaromatic hydrocarbons (PAH) extracted from stormflow runoff from Lincoln Creek also had substantial effects. However, there was a lesser effect from base flow (Villeneuve, 1997, as cited in Bannerman, 2000), suggesting that some PAHs are more mobile and less likely to be sequestered in the sediments. Recent research indicates that the more soluble PAHs such as benzene and naphthalene are generally more toxic, while larger species bound to sediments exert their effects through bioaccumulation in sediment burrowing organisms (Standley, pers. comm.).

These studies show that urban runoff is toxic when levels of pollutants exceed the threshold particular to a test procedure. Some consider *C. dubia* a most sensitive indicator of toxicity (Waller and others, 1995), so WET sensitivity of *C. dubia* may overstate life cycle sensitivity of other benthic organisms. Sensitivity to long term exposure generally occurs at orders of magnitude below lethality at acute exposure. By inhibiting growth, reproduction, and resistance to stress, sublethal levels of toxic pollutants will have substantial effects on benthic communities and will select for pollutant tolerant taxa.

Undoubtedly, these studies strongly implicate urban runoff toxicity as a factor in the impairment of benthic community structure. Since most of the toxic pollutants such as metals are associated with sediments, measures that reduce TSS are the primary mechanism for reducing toxic runoff pollutants. This can be accomplished by either filtration, infiltration or settling BMPs. The design criterion requires that the storage volume be adequate to treat the vast majority of runoff. It must be stressed that infiltration is not the recommended BMP approach where toxic pollutants are mobile and could contaminate groundwater, as in the case of the soluble forms of zinc, copper, soluble PAHs, and many insecticides.

2.3 IMPACTS OF URBAN RUNOFF NUTRIENTS ON LAKES AND INLAND BAYS

Since free flowing shaded streams obtain their energy inputs from the surrounding riparian forest, benthic macroinvertebrate communities in such streams are generally unaffected by elevated levels of the nutrients phosphorus and nitrogen. However, in still water and slower moving reaches exposed to full sun, stream ecosystems are driven by photosynthesis to metabolize nutrients in the water column. In these conditions, typical of tidal streams and inland bays, nutrient loading from urban runoff can be most damaging. Excess nutrients encourage unrestricted growth of algae, leading to eutrophication. As the algae decompose, they consume available oxygen, resulting in nearly complete anoxia at the bottom in many cases. In marshes and lakes, phosphorus is relatively scarce under natural conditions, so excess phosphorus is the most damaging nutrient. In inland bays where nitrogen is limited, excess nitrogen is generally the most damaging nutrient, although bays can be occasionally phosphorus limited.

Although agriculture is widely documented as the most pervasive source of NPS pollution, urban runoff is also implicated in the pollution of water bodies (Hartigan and others, 1979). While the total area may be less than that of rural regions, urban and suburban regions are thought to contribute higher NPS loadings on a per acre basis than rural watersheds (CPB, 1990). This has been attributed to atmospheric deposition of pollutants and nitrate onto impervious surfaces and fertilization of turf (MDE, 1986), as well as the prevalence of onsite septic systems. Nitrate and phosphate concentrations have been found in runoff from shopping centers at levels similar to those from row crops. Originating from pets, fecal coliform counts can be very high in urban runoff (USEPA, 1984).

Septic systems are responsible for well over half the total suburban nitrate loading, and over one third of the suburban phosphorus loading into the inland bays (Ritter, 1986, as cited in Martin 1998). Largely as a result of widespread use of septic systems, suburban residential uses thus account for the second largest source of excess nitrogen to the bays. In the mid-Atlantic Coastal Plain, groundwater levels of inorganic nitrogen (mostly nitrate) in areas developed with septic systems were found to be identical to those under agricultural fields (Reay and others, 1996). However, even in the relatively developed Indian River Bay, it is recognized that agricultural sources of nitrogen are over three times those from urban land uses (Horsley and Witten, 1998).

These effects of excess nutrient loading obviously impair the entire ecosystems in lakes and inland bays. When hypertrophic conditions occur due to excess nutrients, inland bays become subject to increased frequency of Pfisteria outbreaks, resulting in widespread fish kills and health impacts upon people in contact with infested waters. Beyond their effect upon ecosystems health, these effects have considerable economic implications to fisheries and tourism.

Delaware's inland bays are considered to be the most highly eutrophic estuaries in the Chesapeake Bay region. Previous oyster, soft clam and bay scallop fisheries are now essentially extinct due to habitat loss and poor water quality (CCMP, 1995). Water quality indices and benthic community structure reflect significant impairment, especially in those areas with the least amount of tidal flushing. Dead-end canals constructed for urban areas are particularly impaired, with nearly complete loss of the natural ecosystem. Chemical pollutants in these canals exceed published guidelines in 91% of the sampled areas, and dissolved oxygen levels were below the 5 ppm threshold for aquatic life in 57% of the sampled area (Chaillou and others, 1996).

Urban land uses in the Indian River and Rehoboth bays has doubled from 1986 to 1992. Most of these new urban areas represent conversion of previously forested lands, while the extent of agricultural land uses has remained largely unchanged (Martin and others, 1998). Although agricultural land uses are the primary source of excess nutrient deliveries to the bays, this pattern of land use change suggests that nutrient loading will increase due to development, instead of replacing one source of nutrients with another. Therefore, measures to reduce the amount of nutrients in urban runoff are necessary to avoid further deterioration of Delaware's lakes and inland bays as forested lands are developed.

Since much of the phosphorus in urban runoff is associated with suspended sediments, measures to reduce TSS are the primary mechanism for removal of sediments and particulate phosphorus, using filtration, infiltration, or settling BMPs. On the other hand, much of the total nitrogen (TN) occurs in soluble forms. Likewise, most of the bioavailable phosphate occurs in form of soluble orthophosphate. Therefore, nonstructural BMPS using sedimentation and overland filtration processes do not reduce nitrate or orthophosphate levels substantially. Infiltration BMPs transfer nitrate into groundwater, where it is then eventually discharged as base flow into streams. To varying degrees, wetland, riparian forest buffer and denitrifiyng bioretention BMPs provide mechanisms for removal of nitrate from urban runoff.

2.4 IMPACTS OF URBAN RUNOFF HYDROLOGY ON STREAMBANK STABILITY

Although the toxicity data is suggestive, there do not seem to be any studies that isolate specific toxic effects of urban runoff upon benthic macroinvertebrates from its hydrologic impacts (eg., see Diamond, 1996). While there is ample data from Red Clay Creek implicating PCBs from an industrial discharger, or copper from an abandoned factory in Virginia (Diamond, 1996), these situations are not typical for urban runoff. In the mid-Atlantic region, benthic communities in urbanized watersheds were substantially impaired where no changes in water chemistry were noted, in comparison to those in forested watersheds (Jones and others, 1997). In Ohio, biological impairment was noted in 50% of the stream segments, even though no water quality criteria exceedances were observed (Zucker and White, 1996). Though there may be little doubt about the toxicity of urban runoff to test organisms, Horner and others, (1996) note that changes in stream hydrology and geomorphology resulting from urban runoff are even more pernicious for streams and their benthic communities than runoff toxicity and nutrient loading.

Changes in the character of urban streams in response to urban runoff have been observed for some time. In a landmark study, Hammer (1973) noted that channel cross-sectional areas of urban streams in southeastern Pennsylvania were enlarged by a factor of 10 to 20 times that of rural streams with similar drainage areas. Klein (1979) noted that degradation of Piedmont stream channels in Maryland was correlated with the extent of watershed imperviousness. Krug and Goddard (1986) noted a substantial increase in channel size and sediment delivery in a Midwestern watershed undergoing urbanization. Whipple and others (1991) noted that the extent of erosion of urban streams in Maryland was correlated with the extent of Total Impervious Area (TIA) in the watershed.

Under natural conditions, the flow event that moves the most sediment (known as the maximum of the effective work curve) occurs at an interval from one to two years (Leopold and others, 1964). This recurrence interval corresponds to the natural channel forming event frequency (Wolman and Miller, 1960). The primary impact of urban runoff hydrology is the frequency of bankfull flooding increasing from once every two years or so under natural conditions (Wolman and Miller, 1960) to many times per year after urbanization (Arnold and others, 1980; Booth and Jackson, 1997; Moscrip and Montgomery, 1997).

In Washington, DC, dense urbanization has caused bankfull flooding to occur 10 to 20 times more often than the pre-development frequency (Dunne and Leopold, 1978). Conversion of a watershed in western Washington from forested to medium density residential use (EIA at 29%) is projected to increase the frequency of the 5 year bankfull flood to nearly six times per year (Booth, 1990), nearly a thirty-fold increase in the frequency. This is far greater than the two to six-fold increases reported in earlier studies (Coughlin and Hammer, 1973; Schueler, 1987).

This increase in frequent floods shifts the maximum of the effective work curve to mid-bankfull flow events occurring at least several times per year (MacRae and Rowney, 1992). The increase in frequency of flows above the midbank not only causes erosion of bed material, resulting in channel incision (Harvey and Watson, 1986; Shields and others, 1994); it also over-steepens the banks, so bankfull flooding causes stream banks to erode into the incised channel (Arnold and others, 1980; MacRae, 1991). With roots exposed by bank erosion, remaining riparian trees are more subject to windthrow, further widening the banks (Schueler, 1987). Debris dams are left suspended above the channel, reducing roughness so that even greater downcutting occurs (Booth, 1990). This process is aggravated by the increased magnitude and duration of flows that exceed the critical threshold of non-cohesive materials at the toe of the streambank (MacRae, 1991). As urbanization proceeds, the frequency of these sub-bankfull events exceeding this threshold increases by a factor of roughly three (MacRae and Rowney, 1992), or up to ten (MacRae, 1996). For additional discussion of processes involved in stream channel enlargement due to urban runoff, see USEPA (1997) and CWP (2000).

Another contributing factor is the relatively low suspended sediment load in urban runoff. During centuries of intensive agriculture, sediment delivery rates were very high in the eastern U.S. This caused substantial aggradation as the sediments were deposited in floodplains. Following adoption of conservation practices and conversion of upland areas to fallow or urban land uses in the last half century, upland sediment losses have been substantially reduced (Ferguson, 1996; Ruhlman and Nutter, 1999). As a result, the excess kinetic energy formerly used to transport the sediment is presently available to entrain previously deposited bank and bed sediments. This phenomenon of "hungry" streams amplifies the process of stream incision and bank erosion (Heede, 1986). Gravel bars and riffle areas are buried under the sediments as banks erode (WDE, 1992). It is thought that one half of all suspended sediment in urban stream flow is thus generated by these processes of bank erosion (Yu and Wolman, 1986, as cited in MacRae, 1991). In the easily eroded soils of the San Diego Creek watershed, California, bank erosion has been identified as the source of nearly all the suspended sediments found in the streams (Geosyntec, 2002).

There are other adverse hydrological impacts of urbanization due to increased runoff. In Maryland watersheds, Klein (1979) noted that baseflow decreases as extent of urbanization increases. Ferguson and Suckling (1990) noted a similar relation in a Georgia Piedmont stream. On Long Island, Spinello and Simmons (1992, as cited in CWP, 1995a) noted substantial decreases in base flow in intensely urbanized watersheds. Other reviewers suggest that impervious surfaces may have less impact upon baseflow (WEF and ASCE, 1996). This may be due to the fact that although there may be less recharge, there is also is less evapotranspiration from urban sites, so the net effect is not as large as would be expected.

Klein (1979) also noted that summertime water temperatures increased in urban streams. He attributed this to the absence of shade since channels were wider and shallower, and to the reduction in relatively cool baseflow inputs. Urban runoff from paved surfaces and rooftops can be very warm, eliminating cold-water species that are intolerant of warm temperatures (Galli, 1990). Elevated temperatures during summer low flow conditions in urban streams can drive down the concentration of dissolved oxygen to very low levels, resulting in displacement of intolerant species by rough fish that can endure the conditions. In extreme cases during summertime droughts, dissolved oxygen levels can fall so low as to not even support aquatic life, resulting in fish kills. Warmer temperatures also accelerate the release of soluble fractions of zinc, copper, and PAHs into the water column from the sediment pool, further stressing benthic communities and fish.

2.5 IMPACTS OF URBAN RUNOFF HYDROLOGY ON BENTHIC COMMUNITIES

There is a considerable literature documenting the impacts of these changes due to urban land uses upon the resulting benthic macroinvertebrate communities and fisheries. Sedimentation impacts on fisheries can be severe, as the natural sequences of riffles and pools are lost, eliminating spawning areas (WDE, 1992), and reducing salmonid populations (Moscrip and Montgomery, 1999). Siltation in streams is now implicated as the leading cause of impairment to streams (USEPA, 1998).

In Washington, Booth and Jackson (1997) noted substantial declines in fish habitat as effective impervious area (EIA, the impervious areas piped directly to streams) exceeded 8% to 10%. Sediments have been shown to reduce the growth and fecundity of benthic macroinvertebrates, with complete mortality when deposits exceed 10 mm (Sweeney, 1993). Increasing the velocity of flow above 50 cm/sec also eliminates crayfish, resulting in the proliferation of mat-forming algae (Hart, personal comm.), greatly reducing the diatom supply for the remaining invertebrates. As a result, with the adapted food supply and spawning areas greatly reduced or eliminated, desirable native species die off or move away, to be replaced by undesirable opportunistic exotic species (USEPA, 1984; WDE, 1992: and sources cited in Schueler, 1987).

Klein (1979) noted that the species diversity index in streams declined in proportion to the extent of impervious area in the watershed. He attributed the decline to channel enlargement, lowered base flow between storms, and increased temperatures. He also noted the influence of migration barriers and the potential effects of toxic pollutants. He concluded that these effects may be avoided if TIA remains below 15%, or 10% for sensitive stream ecosystems that sustain trout. Numerous other studies have observed this threshold phenomenon of benthic impacts increasing in relation to the extent of watershed imperviousness (eg., Maxted and Shaver, 1997).

In Washington, channel incision and bedload resuspension due to urban runoff has been implicated as the major factor in the destruction of aquatic habitats (WDE, 1992). In the Piedmont area of Pennsylvania, sediments are the foremost pollution problem in aquatic systems (Sweeney, 1993). This can have far reaching consequences, leading to the impairment of economically important fisheries (CPB, 1992). Pederson and Perkins (1986) noted a decline in diversity due to urbanization as benthic taxa shifted from runoff intolerant shredders to runoff tolerant worms. They attributed this shift to the dominance of a silty erosional/depositional substrate in the urban streams, as well as to the absence of leaves, which were rapidly swept away by the increased flooding in the urban flow regime. Horner and others, (1996) noted a considerable reduction in benthic diversity as TIA approached 10%. In Mississippi, Shields and others (1994) noted a similar decline in habitat due to incision.

In Delaware, Maxted (1996) noted that the benthic community index declined substantially once 10% to 15% of a watershed was urbanized. The extent of this impairment was closely correlated with habitat index based upon observations of bank stability, width/depth ratios, point bars, and other evidence of erosion processes (Maxted and Shaver, 1997, 1999).

2.6 MITIGATION OF RUNOFF IMPACTS BY NONSTRUCTURAL BMPs

The preceding discussion emphasizes the urgent need to reduce the impacts of urban runoff. For too long, the toxic and hydrological consequences of urban runoff have been ignored, with unconscionable impacts upon the receiving waters. Even when water quality structural BMPs were finally mandated in 1991, they did not seem to mitigate the decline in benthic macroinvertebrate communities in the receiving waters (Maxted and Shaver, 1997, 1999). Few studies have investigated the impact of the BMPs on receiving waters, but it is thought that warm, algae laden effluent from wet ponds alters the composition of the benthic community in the receiving stream (Jones and others, 1997, and sources cited therein). Furthermore, thermal effects on streams receiving effluent from unshaded wet ponds can be substantial (Van Buren and others, 2000). A recent review by Horner and others (2000) also suggests that structural BMPs are not as effective as a continuous riparian buffer of native vegetation. This is supported by the findings of Zucker and White (1996), where instream biological metrics were correlated with extent of forested buffers.

However, structural pond BMPs do seem to provide habitat protection benefits, (Maxted and Shaver, 1999), so they are definitely an improvement over no BMP at all. In recognition of the need for further improvement, DNREC has formulated the Green Technology methodology to provide a comprehensive approach to the problem.

By using nonstructural BMPs that filter and settle out pollutants in linear landscaped features that provide for tree cover, algal and thermal impacts can be minimized in comparison to large ponds. Furthermore, by integrating these nonstructural BMPs into the landscape, it is possible to provide for more infiltration than is possible for a pond placed at the lowest point in a site. This can have substantial benefits in terms of reducing base flow temperatures, as discussed above. A final benefit is the potential for a nonstructural BMP to be a landscaped amenity, instead of a large isolated structure requiring substantial area for ancillary access, buffering, screening and maintenance facilities.

By defining the problem of urban runoff impacts in such detail, the way to mitigate these impacts becomes more focused. However, to properly address pollutant load impacts, it is necessary to have a realistic idea of the extent of pollutant loads that can be anticipated from the various urban land cover categories. Chapter 3 examines the literature on pollutant loads from such land covers so as to project the most likely loads of pollutants in urban runoff.

CHAPTER 3 URBAN RUNOFF LOADING

3.1 RUNOFF POLLUTANT LOADING OVERVIEW AND MODEL APPROACH

Urban runoff pollutants comprise many different types of chemical compounds, as discussed in Chapter 2. Runoff from parking lots and streets has been shown to have a greater correlation with impacts on urban streams than that from roofs (Coughlin and Hammer, 1973). Toxic metals such as lead, copper, and zinc associated with vehicular uses have been found in 96% of the samples in the metropolitan Washington area (MDE, 1986). Although newer urban areas are typically minor sediment generators, decaying pavement contaminated with particles from tire wear can be the dominant component in runoff in older urban sites (Myers and others, 1985; Harper, 2002).

The pollutants in urban runoff of most concern are total suspended sediments (TSS), total phosphorus (TP), and total nitrogen (TN). Copper and zinc seem to be the most prevalent metals found at toxic levels (Cooke and others, 1994). Most metals and the particulate fractions of nutrients have a high affinity with suspended sediment, so methods to reduce TSS loadings will also tend to reduce loadings of these compounds. For this reason, nitrogen and phosphorus have been segregated into soluble and particulate fractions.

Settling in bioretention facilities, and filtration in filter strips and biofiltration swales are effective methods for treating particulate pollutants. However, for soluble toxic metals such as soluble fractions of zinc and copper, settling is not effective. Zinc can be quite soluble at the pH of urban runoff, as are dissolved copper, volatile organic compounds (VOCs), and many PAHs. These pollutants from "hot spots" such as automotive service centers, certain industrial sites, and high intensity commercial sites such as convenience stores are not removed by settling processes. For these soluble toxic pollutants, bioretention facilities, and/or a treatment train approach is necessary.

Depending upon the land cover in the source area, different amounts of various pollutants will be washed off during runoff events. Using values for average annual mass loads by land cover category alone can introduce substantial error for pervious surfaces, since the volume of runoff varies greatly in response to soil type. This variation is quite substantial at the low rainfall volumes generated by the quality storm discussed in Chapter 4.

To better estimate pollutant loading by different land covers according to their respective areas, it is thus more accurate to delineate expected pollutant loading from each category of urban land cover in terms of its area weighted event mean concentrations (EMCs). The weighted EMC values can then be multiplied by the runoff volume from each category of urban land cover polygons. This product represents the mass load for each individual combination of land cover/soil type during a runoff event. This method accounts for the variation in runoff volumes generated from the extensive combinations of land covers and soil types discussed in Chapter 5.

However, EMCs from differing land cover categories vary widely from event to event, from region to region, and from study to study. When pollutants have accumulated after periods of dry weather, the earliest runoff often has elevated pollutant levels, while EMCs from runoff later in the event or from subsequent events are much lower (Novotny and others, 1994; Soeur and others, 1994). Although less prevalent in events from large basins, (Characklis and Weisner, 1997), this "first flush" phenomenon is often found at the site scale addressed by this Manual. Examination of the literature also indicates that concentrations are generally higher in the smaller events, or events that occur during drier years. EMC values thus can vary over several orders of magnitude between the highest and lowest values observed (see data presented Waschbush and others, 2000). Therefore, continuous simulation models such as SLAMM and PCSWMM use Monte Carlo methods based upon a random number generator to generate a range of loading values that changes from event to event, and take into account pollutant accumulation and washoff functions based upon interevent intervals.

Since DURMM is based upon a single event approach, the option to use a range of values is not available. If the intent is to replicate a "typical" event, it is essential to derive the proper value for the EMC. The arithmetic mean of observations is often reported in many studies. More recent studies report the geometric mean as well, since it weights extreme values less, and thus reveals the central tendency better than the arithmetic mean. However, for the purposes of a single event model, the best approach is to add up the total loads generated over a year, and divided by the annual runoff volume. This "flow-weighted" mean thus reflects the "average" event. By using an annual flow-weighted mean, the inherent variability between events is balanced out over the course of a year.

The runoff volume approach discussed in Chapter 5 can be used to determine runoff volumes of individual land uses to obtain the flow-weighted mean. Where annual loads and runoff volumes are supplied in several studies, flow-weighted means were able to be determined, as indicated in Tables 3-1 through 3-4. Tables 3-1 through 3-4 include these flow-weighted means along with the arithmetic and geometric means reported in the literature. This approach not only provides another reasonable estimate for the typical EMC, it further reinforces the central tendencies. The arithmetic, geometric and flow-weighted means reported in the studies were then used as the basis for establishing the values used in DURMM. Values were adjusted in relation to the geometric mean as discussed below if warranted by further examination.

Total impervious loads are determined by summing up the product of event runoff, times the EMC from each category of impervious area, times area of each category. A similar approach is taken for pervious loads. Total pollutant load is then the sum of impervious and pervious loads. Mass loading thus estimated from the pervious and impervious surfaces is added together to determine total mass loading, which is then divided by total runoff volume to provide the EMC from the site. To the extent that impervious disconnection (discussed in Chapter 5) reduces total runoff, the total loads are then reduced proportionately. EMCs into the BMP are then determined by total load divided by total runoff.

3.2 RUNOFF POLLUTANT TRANSPORT PROCESSES

Note that the EMC values addressed in this Manual are exclusively allocated for surface runoff concentrations. In impervious areas, overland flow dominates the runoff response. However, in largely pervious areas, up to 80% of all annual runoff can occur through subsurface flow pathways, ending up as recharge to base flow (Correll and others, 1997). This situation is typical of watersheds throughout the East, where most streamflow comprises groundwater that has infiltrated previously. Therefore, subsurface pollutant loads can be an important contribution to total annual loads, particularly in agricultural settings.

One of the most effective BMPs is impervious area disconnection, where flow from impervious areas is directed over lawns and other pervious surfaces. For most pollutants, EMCs from impervious surfaces will be substantially reduced where infiltrated through a vegetated root zone overlying an intact soil profile. Vegetative uptake and microbial immobilization transform and sequester nutrients, toxic metals and PAHs. However, once past the root zone, highly soluble pollutants that are not adsorbed by soils can pass into groundwater relatively unaltered.

Parmer and others (1995) reviewed the literature in terms of the potential impacts of urban runoff constituents to groundwater. Nitrate is the most soluble nutrient, while dissolved zinc is the most soluble metal. Depending upon half-life and adsorption coefficients, many pesticides can also infiltrate into groundwater. Organophosphate pesticides are less persistent, but less likely to be adsorbed than organochlorine pesticides. Road salts are very soluble, and minimal reductions in runoff EMCs are observed in BMPs.

Therefore, if heavily polluted runoff is treated by underground infiltration facilities without extensive pretreatment, there is a real concern for groundwater pollution. This is an important consideration for soluble metals and PAHs (Pitt and others, (1996). Nitrate is also very soluble and has minimal uptake by mineral soils. Phosphorus is generally readily bound within the soil profile, even under the very high loads of septic systems (see sources cited in Gold and Sims, 2000). The extent of phosphorus and metals adsorption is quite dependent upon soil properties, as discussed in more detail for bioretention facilities in Chapter 11.

Where infiltration dominates the runoff response, nitrate leaching losses can comprise the majority of total nutrient loading from urban runoff. At present, there are relatively few studies of nitrate leaching losses in urban settings. Most of the literature on urban runoff EMCs focuses on overland flow collected by weirs and other types of collectors. However, there are several that examine leaching losses of nutrients from turf.

Unlike agricultural crops, which are plowed up annually, the well-established root systems of lawns are effectively permanent, so nutrients remain bound up in the shallow soil profile. As a result of nitrate being taken up and/or immobilized in the root zone of the grasses, these studies report minimal leaching losses under normal fertilization and irrigation practices. Average annual flow-weighted loss for typical turf has been reported as low as 0.21 mg/l (Gold and others, 1990) to 1.06 mg/l (Geron and others, 1993). An EPIC simulation of soils thoroughly irrigated with well water at 6.3 mg/l projected a flow-weighted mean of 0.48 mg/l for heavily fertilized fairways (King and Balogh, 1999). Concentrations from over-fertilized sandy soils under excessive irrigation can be as high as 45 mg/l (Watts and others, 1993), but this is not representative of the typical situation.

It is important to note that the volume of rainfall infiltrated into urban lawns typically exceeds the volume that runs off by a factor of at least two (King and Balogh, 1999) or over ten (Kussow, 2002). Several studies show very little runoff from turf, unless frozen (Kussow, 2002) or previously saturated, under high rainfall depths or intensities (Gross and others, 1990; Cole and others, 1997). Depending upon the soil type and climate, leaching loads vary from one-third the runoff losses (King and Balogh, 1999) to over four times the runoff losses (Linde and Watschke, 1997).

Given this variability, and the difficulty in establishing an approach to replicate such interactions, consideration of subsurface losses is beyond the scope of the surface runoff processes addressed in this Manual. DURMM takes the oversimplified approach of omitting groundwater loading in its entirety. However, since such subsurface losses can be substantial, they should be recognized in selecting the appropriate BMP.

For these reasons, the approach in this Manual is to provide a quantitative estimate of total pollutant loads in surface runoff according to their EMCs, so as to identify the location and degree of potential impacts, and provide direction as to the most appropriate approach to mitigate these impacts. By comparing loading EMCs, receiving water criteria, and site constraints, the proper choice of BMPs becomes evident. For instance, infiltration trenches would be discouraged where EMCs of nitrate or soluble metals are high, while bioretention facilities would be recommended. DURMM thus provides for designers to focus on the optimal BMPs by taking into account implications of individual land cover categories and their runoff response. This approach advances BMP design beyond that offered by a generalized land use approach and simplified runoff volume estimates.

3.3 URBAN RUNOFF POLLUTANT LOADING ESTIMATES

Given that this approach is to segregate and estimate runoff EMCs by category of pervious and impervious urban land covers, the literature has been reviewed to determine the most appropriate value to allocate for each type of land cover. However, the literature on EMCs by land cover type is quite thin. There have been numerous studies of different land covers aggregated into certain land uses, but most do not provide information on which land cover (roofs, parking, loading, streets, sidewalks, lawns, landscaping, etc.) is responsible for which proportion of the total load.

Tables 3-1 through 3-5 summarize much of the literature published on urban runoff pollutant loading by land cover. Tables 3-1 and 3-2 summarize TSS loading and phosphorus species loading, and Tables 3-3 and 3-4 summarize nitrogen species loading. Table 3-5 summarizes Copper and Zinc loads, along with information on the location and method of the sources, and where flow weighted data has been included. Agricultural land cover categories are included in these tables since they represent pre-development conditions.

Note that the TSS value allocated for lawns is a relatively high value of 125 mg/l. While TSS EMCs reported from vegetative filters and biofiltration swales can be as low as 4 mg/l, the higher value represents a "typical" urban lawn that may have some bare patches. A lower value could be justified for fairways or well maintained lawns. Likewise, there is a considerable variation in TSS values from streets. The value in Table 3-1 is close to the observed geometric mean, but much lower than the 340 mg/l needed to calibrate the SLAMM model (Waschbusch and others, 2000). Surprisingly, low volume streets seem to have the higher TSS EMCs, and driveways have the highest EMCs of all impervious surfaces. Since the flow weighted TSS varied from 54 mg/l for low tree canopy streets to 211 mg/l for high tree canopy streets, this trend may reflect TSS contributions by adjacent street trees.

Phosphorus loadings in Tables 3-1 and 3-2 are segregated into soluble and insoluble forms so as to segregate the fractions of total phosphorus loads that settle out from that which remains dissolved. Note that most observations provided only total and dissolved values, so EMCs of the particulate fraction has been calculated by subtraction.

Surprisingly high values are reported for phosphorus losses from woods, even though the undisturbed environment of a well-established litter layer would suggest that little phosphorus would be lost in runoff. (Note that the volume of annual runoff from woods is usually so low that annual loads remain very low.) However, Garn (2002) noted that high levels were found in runoff from wooded sites next to lawns. Waschbusch and others (2000) also note a strong correlation between phosphorus EMCs on streets and the extent of tree cover along streets. In urban streets, decomposition pathways that normally recycle nutrients do not occur. Instead, after leaves fall on impervious surfaces, they are broken down by largely mechanical processes and pass into urban runoff relatively unaltered. Table 3-2 also shows that EMCs of dissolved phosphorus from lawns in a basin with extensive tree cover was almost twice that of the lower canopy basin.

For this reason, soluble phosphorus loading from landscaping is allocated value of 1.10 mg/l, twice the 0.55 mg/l assigned to lawns. Likewise, particulate phosphorus from landscaping is allocated at 2.50 mg/l, over three times that from lawns. Using such a high value provides a mechanism, although over-simplified, to account for the effect of phosphorus loads from landscaping upon adjacent categories without having to adjust their EMCs directly. Instead, the designer can allocate the area of landscaping as a separate category from the underlying lawns.

Total nitrogen loads are partitioned into nitrate, ammonium and organic nitrogen loads. TKN is not addressed, as it is the sum of ammonium and organic loads. TN and TKN loads are not addressed individually. Note that many observations only provide partial measurements, so EMCs of the remaining species have been calculated by subtraction.

Since vegetation is absent in impervious surfaces, most of the nitrogen species in runoff from impervious surfaces would seem to be generated from atmospheric deposition. Averaged over a 17 year period at Wye, MD, Correll and others (1994) noted atmospheric inputs of 5.56 kg/ha/yr of nitrate-N, 3.18 kg/ha/yr of ammonium-N and 3.62 kg/ha/yr of organic nitrogen-N. Note that organic N load was 41% of the nitrate and ammonium loads. Given average annual rainfall of 1.08 meters, these values represent 0.51, 0.29 and 0.34 mg/l, respectively.

Table 3-1: Mean TSS and Total Phosphorus EMCs in Urban and Agricultural Runoff (mg/l)

	TOTAL SUSPENDED SOLIDS											
SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO-TILL	PAS-TURE
Owens et al, 1983												160
Polls and Lanyon, 1976				266				34				
Peterjohn and Correll, 1984									6480			
Laflen and Tabatabai, 1984									18940	9710	4940	
Langdale et al, 1985									2310	970		
Correl et al, 1984												
Gilliam et al, 1993a									4111			
Gilliam et al, 1993b									4103			
Correl et al 1994												
Mendez et al, 1999									7890			
Linde and Watschke, 1997						15						
Gross et al, 1991						231						
Gross et al, 1990						25						
Gross et al, 1990						8						
Horner et al, 1994			45					1				
Garn, 2002												
Schueler & Shepp 1993			11	3								
Pitt et al 1996a				450	310	118						
Pitt et al 1996b		0		136	687	807						
Pitt, et al, 1996	3	27	16	15			38					
DSWF, 1996	9	19	27	172	173	602	37					
Wisconsin, 1992	19	36	474	241	193	457						
Bannerman et al, 1993	15	27	58	326	173	397						
Steuer et al, 1997	24	36	138	305	157	262						
Waschbusch et al, 1999a	18	16	51	69	34	91						
Waschbusch et al, 1999b		20		211	68	128						
Waschbusch et al, 1999c	21	18	75	94	266	77						
Waschbusch et al, 1999d	21	20	75	94	255	88						
Arithmetic Mean	16	22	97	183	232	236	37	18	7306	5340	4940	160
Geometric Mean	14	14	54	111	177	121	37	6	5791	3069	4940	160
MODEL VALUE	15	20	60	110	180	125	50	30	6000	3000	1000	160

	TOTAL PHOSPHORUS											
SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO-TILL	PAS-TURE
Owens et al, 1983												
Polls and Lanyon, 1976												
Peterjohn and Correll, 1984									5.03			
Laflen and Tabatabai, 1984												
Langdale et al, 1985									0.08	0.17		
Correl et al, 1984								0.81	0.16			0.56
Gilliam et al, 1993a									1.70			
Gilliam et al, 1993b									2.14			
Correl et al 1994								0.35		2.32		0.81
Mendez et al, 1999												
Linde and Watschke, 1997												
Gross et al, 1991												
Gross et al, 1990												
Gross et al, 1990												
Horner et al, 1994			0.08					0.10				
Garn, 2002						2.06	3.52					
Schueler & Shepp 1993			0.50	0.06								
Pitt et al 1996a				0.30	0.63	0.29						
Pitt et al 1996b		0.04		0.49	0.62	0.20						
Pitt, et al, 1996												
DSWF, 1996	0.20	0.09	0.45	0.63	1.16	1.67						
Wisconsin, 1992	0.24	0.19	0.48	0.53	1.50	3.47						
Bannerman et al, 1993	0.20	0.15	0.19	1.07	1.16	2.67						
Steuer et al, 1997	0.09	0.06	0.20	0.23	0.35	2.33						
Waschbusch et al, 1999a	0.07	0.11	0.05	0.32	0.18	1.20						
Waschbusch et al, 1999b		0.16		0.76	0.24	1.54						
Waschbusch et al, 1999c	0.13	0.07	0.11	0.38	0.50	1.05						
Waschbusch et al, 1999d	0.13	0.12	0.11	0.38	0.47	1.13						
Arithmetic Mean	0.15	0.11	0.24	0.47	0.68	1.60	3.52	0.42	1.82	1.24		0.68
Geometric Mean	0.14	0.10	0.18	0.38	0.55	1.23	3.52	0.30	0.74	0.63		0.67
MODEL VALUE	0.15	0.11	0.25	0.38	0.49	1.30	3.60	0.30	2.30	1.70	1.10	1.30

Table 3-2: Mean Particulate and Soluble Phosphorus EMCs in Urban and Agricultural Runoff (mg/l)

	PARTICULATE PHOSPHORUS												SOLUBLE PHOSPHORUS											
SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO-TILL	PAS-TURE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO-TILL	PAS-TURE
Peterjohn and Correll, 1984									4.82												0.21			
Polls and Lanyon, 1976																0.07				0.04				
Laflen and Tabatabai, 1984																					0.08	0.17	0.60	
Langdale et al, 1985									1.82	0.85											0.13	0.23		
Gilliam et al, 1993a									1.16												0.29			
Gilliam et al, 1993b									1.70												0.44			
Correl et al 1994								0.29		2.27		0.76								0.06		0.05		0.05
Cole et al, 1997																		5.21						
Linde and Watschke, 1997																		3.19						
Gross et al, 1991																		0.06						
Gross et al, 1990																		0.03						
Kussow, 2002																		0.12						
Garn, 2002						1.58	2.48											0.48	1.04					
Schueler & Shepp 1993			0.34	0.05											0.16	0.01								
Pitt et al 1996a				0.24	0.25	0.09										0.06	0.38	0.20						
Pitt et al 1996b		0.02		0.46	0.60									0.02		0.03	0.02	0.66						
Wisconsin, 1992	0.13	0.11	0.41	0.39	0.63	1.07							0.11	0.08	0.07	0.14	0.87	2.40						
Bannerman et al, 1993	0.12	0.09	0.14	0.76	0.67	1.22							0.08	0.06	0.05	0.31	0.49	1.45						
Steuer et al, 1997	0.06	0.04	0.18	0.22	0.31	2.24							0.03	0.02	0.02	0.01	0.04	0.09						
Waschbusch et al, 1999a	0.11	0.06	0.08	0.20	0.11	0.63							0.02	0.05	0.02	0.12	0.07	0.57						
Waschbusch et al, 1999b		0.09		0.42	0.12	0.71								0.09		0.34	0.12	0.85						
Waschbusch et al, 1999c	0.09	0.04	0.09	0.20	0.36	0.56							0.02	0.03	0.03	0.19	0.14	0.49						
Waschbusch et al, 1999d	0.09	0.06	0.09	0.20	0.34	0.58							0.02	0.07	0.03	0.18	0.14	0.55						
Arithmetic Mean	0.10	0.06	0.19	0.31	0.38	0.96	2.48	0.29	2.37	1.56		0.76	0.05	0.05	0.06	0.13	0.25	1.09	1.04	0.05	0.23	0.15		
Geometric Mean	0.10	0.06	0.16	0.25	0.31	0.73	2.48	0.29	2.04	1.39		0.76	0.04	0.04	0.04	0.08	0.14	0.47	1.04	0.05	0.19	0.12		
MODEL VALUE	0.10	0.06	0.20	0.30	0.35	0.75	2.50	0.25	2.10	1.40	0.70	0.75	0.05	0.05	0.05	0.08	0.14	0.55	1.10	0.05	0.20	0.30	0.40	0.55

Table 3-3: Mean Total and Nitrate Nitrogen EMCs in Urban and Agricultural Runoff (mg/l)

	TOTAL NITROGEN												NITRATE NITROGEN											
SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO-TILL	PAS-TURE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO-TILL	PAS-TURE
Peterjohn and Correll, 1984									4.45												4.45			
Laflen and Tabatabai, 1984																					0.18	0.21	1.59	
Correl et al, 1984								0.36	5.26			0.27								0.36	5.26			0.27
Langdale et al, 1985									5.04												5.04			
Gilliam et al, 1993a									0.90												0.90			
Gilliam et al, 1993b									0.83												0.83			
Owens et al, 1983																								1.95
Owens et al, 1989																								0.80
Correl et al 1994								0.14				0.40								0.14		1.61		0.40
Mendez et al, 1999									27.89															
Cole et al, 1997																		2.09						
Linde and Watschke, 1997																		0.42						
King and Balogh, 1997																		2.71						
Gross et al, 1990																		0.27						
Gross et al, 1990																		0.04						
Horner et al, 1994			0.32				0.03								0.32				0.03					
Kussow, 2002																		0.12						
Garn, 2002																		0.12						
Schueler & Shepp 1993			0.01	0.92											0.01	0.92								
Pitt et al 1996a																								
Pitt et al 1996b																								
Steuer et al, 1997	0.49	0.46	0.34	0.32	0.30	0.40							0.49	0.46	0.34	0.32	0.30	0.40						
Arithmetic Mean	0.49	0.46	0.22	0.62	0.30	0.40	0.03	0.25	7.40			0.34	0.49	0.46	0.22	0.62	0.30	0.77	0.03	0.25	2.78	0.91	1.59	0.86
Geometric Mean	0.49	0.46	0.10	0.54	0.30	0.40	0.03	0.23	3.68			0.33	0.49	0.46	0.10	0.54	0.30	0.33	0.03	0.23	1.59	0.58	1.59	0.64
MODEL VALUE	0.50	0.45	0.30	0.55	0.30	0.35	0.25	0.25	1.60	1.80	2.00	0.60	0.50	0.45	0.30	0.55	0.30	0.35	0.25	0.25	1.60	1.80	2.00	0.60

Table 3-4: Mean Ammonia and Organic Nitrogen EMCs in Urban and Agricultural Runoff (mg/l)

SOURCE	AMMONIA NITROGEN: FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO-TILL	PAS-TURE
Peterjohn and Correll, 1984									1.89			
Laflen and Tabatabai, 1984									0.19	0.58	1.23	
Correl et al, 1984								0.98	1.88			0.32
Langdale et al, 1985												
Gilliam et al, 1993a									0.02			
Gilliam et al, 1993b									0.34			
Owens et al, 1983												6.00
Owens et al, 1989												1.60
Correl et al 1994								0.12		0.18		0.15
Mendez et al, 1999									4.30			
Cole et al, 1997						3.65						
Linde and Watschke, 1997						*0.32*						
Gross et al, 1990						0.21						
Gross et al, 1990						0.07						
Homer et al, 1994			0.22									
Gam, 2002						0.96						
Schueler & Shepp 1993			1.58	0.19								
Pitt et al 1996a				0.05	0.10	0.40						
Pitt et al 1996b		0.10		0.05	0.30	0.50						
Steuer et al, 1997	0.67	0.44	0.22	0.35	0.12	0.26						
Arithmetic Mean	0.67	0.27	0.67	0.16	0.17	0.80		0.55	1.44	0.38	1.23	2.02
Geometric Mean	0.67	0.21	0.42	0.11	0.15	0.41		0.35	0.52	0.32	1.23	0.82
MODEL VALUE	0.65	0.25	0.45	0.15	0.15	0.50	0.45	0.40	0.60	1.00	1.70	0.70

SOURCE	ORGANIC NITROGEN: FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	MEDIUM STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO-TILL	PAS-TURE
Peterjohn and Correll, 1984												
Laflen and Tabatabai, 1984												
Correl et al, 1984								2.17	1.65			1.82
Langdale et al, 1985												
Gilliam et al, 1993a									3.43			
Gilliam et al, 1993b									4.27			
Owens et al, 1983												3.55
Owens et al, 1989												2.70
Correl et al 1994								1.39		2.97		3.16
Mendez et al, 1999									23.59			
Cole et al, 1997												
Linde and Watschke, 1997						*1.13*						
Gross et al, 1990												
Gross et al, 1990												
Homer et al, 1994			0.35				0.16					
Gam, 2002												
Schueler & Shepp 1993			3.36	0.65								
Pitt et al 1996a				1.75	2.50	0.80						
Pitt et al 1996b		0.70		1.55	0.80	0.80						
Steuer et al, 1997	0.93	0.56	1.38	0.95	1.68	9.04						
Arithmetic Mean	0.93	0.63	1.70	1.23	1.66	2.94	0.16	1.78	8.23			2.81
Geometric Mean	0.93	0.63	1.18	1.14	1.50	1.60	0.16	1.73	4.89			2.72
MODEL VALUE	0.95	0.65	1.20	1.15	1.50	1.80	1.75	1.75	4.90	5.40	6.00	2.75

Table 3-5: Mean Copper and Zinc EMCs in Urban Runoff (mg/l), Sources

TOTAL COPPER (ug/l)

SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO-TILL	PAS-TURE
CH2MHill, 2000				22.1		5.7		5.3	5.4			5.4
Omni source						9.8			11.3			
Horner et al, 1994			4.5									
Tiefefthaler et al, 2001			28.0									
Cook et al, 1996						10.0						
Pitt, et al, 1996	5.0	46.0	285.0	10.0								
DSWF, 1996	7.0	20.0	51.0	24.0	17.0	17.0						
Wisconsin, 1992	10.0	5.0	21.0	25.0	20.0	13.0						
Bannerman et al, 1993	9.0	15.0	15.0	56.0	17.0							
Steuer et al, 1997	20.0	7.0	22.0	30.0	34.0							
Arithmetic Mean	10.2	18.6	60.9	27.9	22.0	11.1		5.3	8.4			5.4
Geometric Mean	9.1	13.7	27.8	24.6	21.1	10.4		5.3	7.8			5.4
MODEL VALUE	10	15	30	25	25	15	5	5	10	10	10	5

TOTAL ZINC (ug/l)

SOURCE	FLAT ROOFS	PITCHED ROOFS	PARKING LOTS	STREETS	DRIVE-WAYS	LAWNS	LAND-SCAPE	WOODS	CONV. TILL	CHISEL PLOW	NO-TILL	PAS-TURE
CH2MHill, 2000				214.6		25.4		24.8	23.5			23.5
Omni source						75.8			64.0			
Horner et al, 1994			90.0									
Tiefefthaler et al, 2001			293.0									
Cook et al, 1996						200.0						
Pitt, et al, 1996	181.0	476.0	64.0	38.0								
DSWF, 1996	256.0	312.0	139.0	173.0	107.0	50.0						
Wisconsin, 1992	363.0	153.0	249.0	245.0	113.0	60.0						
Bannerman et al, 1993	330.0	149.0	178.0	339.0	107.0							
Steuer et al, 1997	348.0	201.0	178.0	166.0	148.0							
Arithmetic Mean	295.6	258.2	170.1	195.9	118.8	82.2		24.8	43.8			23.5
Geometric Mean	286.5	232.6	151.7	164.0	117.6	64.9		24.8	38.8			23.5
MODEL VALUE	290	240	170	160	120	90	25	25	40	50	60	25

SOURCE	LOCATION, METHOD, COMMENTS
Peterjohn and Correll, 1984	MD- arithmetic means, natural events
Laflen and Tabatabai, 1984	IA- arithmetic mean, simulated events
Correl et al, 1984	MD- arithmetic mean, natural events
Langdale et al, 1985	GA- arithmetic means, natural events
Gilliam et al, 1993a	NC- geometric means, natural events
Gilliam et al, 1993b	NC- flowweighted means, natural events
Correl et al 1994	MD- arithmetic means, buffered stormflow
Mendez et al, 1999	VA- arithmetic means, simulated events
Cook et al, 1996	CA- arithmetic means,, streamflow measurments
Cole et al, 1997	Oklahoma, flow weighted mean, intense simulated
Linde and Watschke, 1997	Oklahoma-flow weighted mean, natural and simulated
Gross et al, 1991	Maryland- flow weighted mean, simulated rainfall
Gross et al, 1990	Maryland- flow weighted mean, dry year events
Gross et al, 1990	Maryland- flow weighted mean, average year events
Horner et al, 1994	Nationwide summary
Kussow, 2002	Wisconsin- flow weighted mean, natural events
Garn, 2002	Wisconsin- average of geometric mean, several events
Schueler & Shepp 1993	Maryland -arithmetic mean, natural events
Pitt et al 1996a	Toronto-arithmetic mean, winter events
Pitt et al 1996b	Toronto -arithmetic mean, warm season events
Pitt, et al, 1996	Alabama- arithmetic mean, natural events
DSWF, 1996	Wisc. & Ala.- arithmetic mean, natural events
Wisconsin, 1992	Wisconsin- geometric mean, several events
Bannerman et al, 1993	Wisconsin- geometric mean, several events
Steuer et al, 1997	Michigan- geometric mean, several events
Waschbusch et al, 1999a	Wisconsin-average geometric mean, many events in two basins
Waschbusch et al, 1999b	Wisconsin- flow weighted mean, many events, wooded basin
Waschbusch et al, 1999c	Wisconsin- flow weighted mean, many events, open basin
Waschbusch et al, 1999d	Wisconsin- flow weighted mean, many events, both basins
CH2MHill, 2000	Recommended EMCs for NC based upon measurments
Tiefefthaler et al, 2001	California, mean of many rainfall simulator events

The Model of the Chesapeake Airshed calls for atmospheric deposition rates of 3.22 and 1.94 kg/ha/yr of nitrate-N and ammonia-N, respectively in Wye, MD (Linker and others, 2000). Based upon the results of Scudlark and Church (1993, as cited in Horsley and Witten 1998) for Lewes, DE, average EMCs for nitrate are 0.28 mg/l and 0.17 mg/l for ammonium. Using a 41% value for organic N, this suggests a value of 0.20 mg/l for the particulate organic component. Compared to the EMCs reported in Steuer and others (1997) and Pitt and others (1996), the inorganic forms of nitrogen predicted from deposition are slightly less than observed EMCs. However, levels of organic N in urban runoff from impervious surfaces seem to exceed atmospheric deposition by a factor of at least three. This suggests that there must be additional sources local to the urban environment. Given a TKN level as high as 9.30 mg/l from lawns (Steuer and others, 1997), lawns (and/or trees) would seem to be the primary source of organic N deposition on adjacent impervious surfaces.

For organic N, the geometric mean of the study residual values is applied to impervious surfaces. For lawns, the residual value of 9.04 from Steuer and others (1997) may represent an extreme when compared to the 0.80 reported by Pitt and others (1996), so a design value of 3.45 is used, based on the geometric mean of the studies. This value is similar to the 3.16 mg/l reported for pastures by Correll and others (1994). Given their turf cover and nutrient inputs, pastures could be considered similar to lawns in this analysis.

In the Rhode River watershed near Wye, MD, organic N from crops was 77% of total N in surface runoff, with 92% in the particulate form. In contrast, groundwater levels of organic-N were only 2.4% of total subsurface N loads (Peterjohn and Correll, 1984). Dillaha and others (1989) noted that 95% to 97% of organic N in runoff from plowed fields was in the particulate form. Organic N comprises 80% of the total nitrogen in stormflow from pastures, and over 50% of the load from crops and woods, while base flow ratios varied from 48% to 26% (Correll and others, 1995). These studies suggest that surface runoff pathways dominate stormflow losses of organic N. This was confirmed in subsequent study in the Maryland Piedmont by the same authors, although they reported that 70-80% of organic N was in a dissolved form (Jordan and others, 1997).

If organic N were particulate, most of the organic N in urban runoff would be in a form amenable to settling and filtration. However, organic N EMC reductions by vegetative filtration BMPs are variable, ranging from 30% to 80% (See Chapter 9). This implies that some of the organic N loads must be either soluble, or adsorbed into fractions too fine to settle with these BMPs. Parsons and others (1993) reported average organic N EMC reductions from 31% to 52% from filter strips below cropped areas. Since this study had events similar to conditions encountered in urban BMPs, the lower range seems more appropriate. It seems that organic nitrogen is present in a fraction too fine to filter thoroughly, but with a low ability to percolate into groundwater.

While the main thrust of DURMM is to address sediment and nutrient loads, there is a potential for toxicity from elevated levels of metals, PAHs, organic compounds, and petroleum hydrocarbons in runoff originating from many development sites. Petroleum hydrocarbons from "hot spots" such as intense industrial and commercial land uses can be quite elevated in comparison to residential streets (Shepp, 1996). A similar relationship was noted for copper and zinc (Schueler and Shepp, 1995). While there is little data on PAH loading by land cover, Steuer and others (1997) noted that total PAHs from parking lots was 90 µg/l, while other impervious surfaces were in the range of 1 to 5 µg/l. No PAHs were noted in runoff from lawns.

Since the literature is just now emerging, the approach taken in DURMM is to wait until better data is available for estimating PAH and organic compound loading from hot spots. Note that the soluble forms of metals are more toxic, but there are no nationwide standards for these species. Table 3-5 summarizes metals loading by land cover.

By defining the extent of urban runoff loads in this method, the requirements needed to mitigate these loads become more focused. However, to more fully address urban runoff impacts, it is also necessary to have a realistic idea of the hydrological impacts of urban runoff. Chapter 4 examines the criteria needed for pollutant removal, and relates these criteria to the Delaware's climate characteristics.

CHAPTER 4 URBAN RUNOFF CRITERIA

4.1 CRITERIA FOR URBAN RUNOFF POLLUTANT TREATMENT

The primary factor in developing treatment criteria for the control of pollutants in urban runoff is to define the runoff volume captured by a water quality BMP. For a treatment process to reduce pollutants to acceptable levels, a BMP must intercept enough of the annual loading of runoff. If the treatment volume is inadequate, it will not provide the necessary benefits that may be otherwise attainable.

The State of Maryland has established goals to reduce TSS loading from urban runoff by 80%, and reduce total phosphorus (TP) loading by 40% (MDE, 1999). It is thought that TSS removal will address most toxic pollutants such as metals, since they are generally associated with sediments. The 80% removal value for TSS implies that the great majority of the annual runoff volume must be captured by a BMP to attain the target level of treatment. In Maryland, roughly 70% of total rainfall occurs in events up to an inch, but an inch of treatment for the larger storms boosts the effective capture volume into the range of 80 to 85% (Prince Georges Co., 2000). Many authorities thus establish a treatment volume at one inch of rainfall as being adequate to attain the desired goals, while still being cost effective (Claytor and Schueler 1996; Prince Georges Co., 2000; MDE, 1999).

The Coastal Zone Management Program recommends treatment of the 2 year, 24 hour storm of over 3 inches (USEPA, 1991). Continuous modeling indicates that nearly as effective treatment could be provided more cost effectively by using a smaller design event, so Wisconsin recommends a design event in the range of 1.25 to 1.5 inches (WDNR, 1995). However, rules proposed to be adopted by the USEPA for marinas and agricultural areas require treatment of 80% of the annual runoff, not annual rainfall. Since pervious areas generate much less runoff than impervious areas at low rainfall amounts, the required rainfall volume to capture 80% of runoff will be greater in sites with more pervious area.

Table 4-1 displays the percentage of annual rainfall volume during events of the indicated size increment at Porter Reservoir in New Castle Co., Dover in Kent Co., and Georgetown in Sussex Co. (Leathers, 2000). Precipitation increment is the product of the average rainfall in each increment and its percent of total rainfall. Note that the final rainfall increment for extreme events is larger, since these events provide 0.3% to 0.6% of total annual rainfall. At rainfall increments greater than the recommended capture depth of 2.0 inches, captured precipitation is the product of capture depth times the incremental percentage of annual rainfall. The amount of annual rainfall captured by a specific volume is then determined by summing across the rows. Depending upon location, a treatment volume of 2.0 inches intercepts 95% to 97% of annual rainfall.

Table 4-1: Annual Precipitation Distribution and Runoff Capture Volumes of the 2.0 Inch Event, New Castle, Kent And Sussex Counties, Delaware

LOWER INCREMENT	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	TOTAL
UPPER INCREMENT	0.24	0.49	0.74	0.99	1.24	1.49	1.74	1.99	2.24	2.49	2.74	2.99	6.00	
PORTER RESERVOIR, NEW CASTLE COUNTY														
UNADJUSTED %	58.0%	17.0%	10.0%	6.0%	4.0%	2.0%	1.0%	0.7%	0.6%	0.5%	0.3%	0.1%	0.3%	100.5%
ADJUSTED %	57.7%	16.9%	10.0%	6.0%	4.0%	2.0%	1.0%	0.7%	0.6%	0.5%	0.3%	0.1%	0.3%	100%
INCRMNT. PRECIP.	6.93	6.26	6.17	5.19	4.46	2.73	1.61	1.30	1.27	1.18	0.78	0.29	1.34	39.5
PRECIP. CAPTURE	6.93	6.26	6.17	5.19	4.46	2.73	1.61	1.30	1.19	1.00	0.60	0.20	0.60	38.2
IMPERV. EVENT	0.04	0.19	0.37	0.59	0.82	1.05	1.30	1.54	1.79	2.04	2.29	2.54	4.17	
IMPERV. ANNUAL	2.48	3.13	3.71	3.50	3.25	2.10	1.29	1.07	1.07	1.01	0.68	0.25	1.24	24.8
IMPERV. CAPTURE	2.48	3.13	3.71	3.50	3.25	2.10	1.29	1.07	0.86	0.73	0.45	0.15	0.37	23.1
PERV. EVENT	0.00	0.00	0.00	0.02	0.04	0.08	0.12	0.17	0.23	0.29	0.36	0.44	1.09	
PERV. ANNUAL	0.00	0.00	0.02	0.11	0.17	0.15	0.12	0.12	0.13	0.12	0.08	0.03	0.15	1.2
PERV. CAPTURE	0.00	0.00	0.02	0.11	0.17	0.15	0.12	0.12	0.10	0.09	0.05	0.02	0.04	1.0
50% PERV. ANNUAL	1.24	1.57	1.86	1.81	1.71	1.13	0.70	0.60	0.60	0.57	0.38	0.14	0.69	13.0
50% PERV. CAPTURE	1.24	1.57	1.86	1.81	1.71	1.13	0.70	0.60	0.48	0.41	0.25	0.09	0.21	12.0
CAPTURE PERCENT	PRECIPITATION			96.8%	IMPERVIOUS		93.2%	PERVIOUS		83.2%	50% COMBINED			92.7%
DOVER, KENT COUNTY														
UNADJUSTED %	53.0%	18.0%	11.0%	6.0%	4.0%	3.0%	1.0%	0.9%	0.8%	0.6%	0.2%	0.2%	0.5%	99.2%
ADJUSTED %	53.4%	18.1%	11.1%	6.0%	4.0%	3.0%	1.0%	0.9%	0.8%	0.6%	0.2%	0.2%	0.5%	100%
INCRMNT. PRECIP.	6.41	6.71	6.88	5.26	4.52	4.14	1.63	1.70	1.71	1.43	0.53	0.58	2.27	43.8
PRECIP. CAPTURE	6.41	6.71	6.88	5.26	4.52	4.14	1.63	1.70	1.61	1.21	0.40	0.40	1.01	41.9
IMPERV. EVENT	0.04	0.19	0.37	0.59	0.82	1.05	1.30	1.54	1.79	2.04	2.29	2.54	4.17	
IMPERV. ANNUAL	2.30	3.36	4.13	3.55	3.29	3.19	1.31	1.40	1.44	1.23	0.46	0.51	2.10	28.3
IMPERV. CAPTURE	2.30	3.36	4.13	3.55	3.29	3.19	1.31	1.40	1.16	0.89	0.30	0.31	0.63	25.8
PERV. EVENT	0.00	0.00	0.00	0.02	0.04	0.08	0.12	0.17	0.23	0.29	0.36	0.44	1.09	
PERV. ANNUAL	0.00	0.00	0.02	0.11	0.18	0.23	0.12	0.15	0.18	0.18	0.07	0.09	0.55	1.9
PERV. CAPTURE	0.00	0.00	0.02	0.11	0.18	0.23	0.12	0.15	0.15	0.13	0.05	0.05	0.17	1.4
50% PERV. ANNUAL	1.15	1.68	2.08	1.83	1.73	1.71	0.71	0.78	0.81	0.70	0.27	0.30	1.33	15.1
50% PERV. CAPTURE	1.15	1.68	2.08	1.83	1.73	1.71	0.71	0.78	0.65	0.51	0.18	0.18	0.40	13.6
CAPTURE PERCENT	PRECIPITATION			95.7%	IMPERVIOUS		91.3%	PERVIOUS		71.8%	50% COMBINED			90.1%
GEORGE TOWN, SUSSEX COUNTY														
UNADJUSTED %	56.0%	17.0%	10.0%	6.0%	4.0%	2.0%	1.0%	0.7%	0.5%	0.4%	0.2%	0.2%	0.6%	98.6%
ADJUSTED %	56.8%	17.2%	10.1%	6.1%	4.1%	2.0%	1.0%	0.7%	0.5%	0.4%	0.2%	0.2%	0.6%	100%
INCRMNT. PRECIP.	6.82	6.38	6.29	5.29	4.54	2.78	1.64	1.33	1.08	0.96	0.53	0.58	2.74	41.0
PRECIP. CAPTURE	6.82	6.38	6.29	5.29	4.54	2.78	1.64	1.33	1.01	0.81	0.41	0.41	1.22	38.9
IMPERV. EVENT	0.04	0.19	0.37	0.59	0.82	1.05	1.30	1.54	1.79	2.04	2.29	2.54	4.17	
IMPERV. ANNUAL	2.44	3.19	3.78	3.57	3.31	2.14	1.32	1.10	0.91	0.83	0.46	0.51	2.54	26.1
IMPERV. CAPTURE	2.44	3.19	3.78	3.57	3.31	2.14	1.32	1.10	0.73	0.60	0.30	0.31	0.76	23.5
PERV. EVENT	0.00	0.00	0.00	0.02	0.04	0.08	0.12	0.17	0.23	0.29	0.36	0.44	1.09	
PERV. ANNUAL	0.00	0.00	0.02	0.11	0.18	0.16	0.12	0.12	0.11	0.12	0.07	0.09	0.67	1.8
PERV. CAPTURE	0.00	0.00	0.02	0.11	0.18	0.16	0.12	0.12	0.09	0.09	0.05	0.05	0.20	1.2
50% PERV. ANNUAL	1.22	1.60	1.90	1.84	1.74	1.15	0.72	0.61	0.51	0.47	0.27	0.30	1.60	13.9
50% PERV. CAPTURE	1.22	1.60	1.90	1.84	1.74	1.15	0.72	0.61	0.41	0.34	0.18	0.18	0.48	12.4
CAPTURE PERCENT	PRECIPITATION			95.0%	IMPERVIOUS		90.2%	PERVIOUS		67.0%	50% COMBINED			88.8%

Table 4-1 also displays capture volumes in terms of percentages of annual runoff, instead of annual rainfall. Event runoff is calculated according to the methods described in Chapter 5, using the average rainfall depth for each increment. Runoff volumes are presented for impervious surfaces with a curve number of 98, pervious surfaces at a curve number of 61, and a combined area that is 50% pervious. Annual depth is incremental rainfall multiplied by the proportion of runoff to rainfall at each increment. At rainfall increments greater than the capture depth of 2.0 inches, captured runoff is the product of annual depth times the ratio of capture depth to upper increment of annual rainfall, less 10% to account for the fact that runoff is less than rainfall. (Actual values of this relationship vary from 5% to 16%, depending upon depth.)

Depending upon the rainfall distribution, 2.0 inches of rainfall capture captures 90% to 93% of the annual runoff from impervious surfaces, but only 67% to 83% from the pervious surfaces. However, when impervious areas are 50% of the total, the total runoff capture percentage ranges from 89% to 93%. This is due to the fact that runoff from impervious areas is much greater than that from pervious areas, exceeding pervious runoff volumes by over a factor of 10. For this reason, changes in pervious curve numbers do not affect the total percentages materially. A capture depth of 2.0 inches thus ensures treatment of at least 80% of annual runoff for the typical development site in which impervious surfaces comprise at least 35%. If the capture threshold were a smaller rainfall event, such as 1.0 inch, the annual capture volume from low-density sites would be less than 80 percent.

Given that BMPs are not 100% effective (typically 80-95% for TSS, 40-60% for total phosphorus, and 0-30% for total nitrogen), this implies that a higher percentage of annual rainfall volume should be captured by a BMP to attain target levels of treatment. If the intent is to provide an 80% reduction in annual loads, the capture percentage has to be multiplied by treatment efficiency. At an efficiency of 90%, reductions in TSS loads would be 83%, 80% and 81% for 50 percent impervious sites in New Castle, Sussex, and Kent Counties, respectively. Since these values correspond to an 80% target, this analysis suggests that a treatment volume of at least 1.5 inches is necessary. This corresponds to the findings established in Wisconsin (WDNR, 1995).

BMPs will provide for more treatment and last longer when the treatment volume is thus increased by 100% over the one inch typically used. Furthermore, BMPs properly designed for a volume of 2.0 inches can often route larger flood flows effectively with a relatively small increase in total storage volume. Such BMPs also provide for extensive contact filtering and the opportunity for infiltration of runoff. Therefore, Green Technology recommends that runoff quality BMPs should be designed to capture and treat runoff volumes for storm events up to 2.0 inches of rainfall.

To promote recharge, designers are encouraged to install BMPs that recharge the losses in recharge volumes due to development. Since this can be difficult in certain sites, recharge is not a requirement of this Manual. Wherever recharge is not a viable option due to site conditions, extended detention of the 2.0 inch volume is recommended, as discussed in more detail in Section 4.2.

4.2 CRITERIA FOR STREAM BANK PROTECTION HYDROLOGY

The need to mitigate the changes in hydrology from urbanization is thus particularly important. Regardless of whether pollutants are present, healthy benthic communities cannot exist in unstable streams. Therefore, measures to alter urban hydrologic responses to that which the receiving stream can tolerate are vitally important to the health of streams. The following discussion sets forth the background and rationale for criteria to protect instream habitat.

In typical soils, infiltration of the entire increase in runoff volume is rarely feasible in developments where imperviousness exceeds 20% or so. Therefore, extended detention of the frequent runoff events is the best option available to minimize downstream bank erosion. As a result, Ontario regulations have required Overcontrol (OC) of the one inch storm by retaining this volume over a 24 hour period. However, too much OC by itself can cause aggradation, which also destabilizes streambanks. Instead, MacRae (1991) recommends the Distributed Runoff Control (DRC) approach, in which the retention structure is designed to increase OC volumes to reduce post-development flows by at least 50% below pre-development flows, at stages below midbank flows. The outflow increases to equal pre-development peak flows of the two-year storm at the bankfull flows. This provides a substantial reduction in the erosional potential of sub-bankfull flows, while allowing the flows at the higher stages to flush out accumulated sediments.

Since midbank flows are the dominant flows causing bank erosion, the midbank flow rate is used as the pre-development target criterion for the 50% over-control release rate. Assuming that the two-year recurrence interval event represents bankfull discharge, and that mid to upper bank flows approach 50% of this flow, design flow would occur at precipitation events in the range of 1.4 to 1.7 inches, representing a recurrence frequency of several times per year. Since these values are close to the 2.0 inches required for quality treatment, Green Technology recommends a reduction in the peak rates from pre-development flows from the storm of 2.0 inches of rainfall, and no increase in the 2 year peak runoff rate.

However, the appropriate DRC reductions from pre-developed flows and the criteria for pre-development conditions are more difficult to establish. Booth and Jackson (1997) note that the threshold for impacts from urbanization occurs at a 10% effective impervious area (EIA), or 20% total impervious area (TIA) typical of medium density single family homes. Using the HSPF model, Booth and Jackson also noted that this threshold was equivalent to a Q_{2post} (post-development peak flow rate from the two-year storm) being equal to or less than Q_{10pre} for forested areas. This tolerance value implies that forested streams could convey up to a 60% increase in flows (the difference between Q_2 and Q_{10}) before destabilization occurs. The 10% EIA threshold seems to correlate well with the 10% to 15% TIA threshold for habitat impacts noted for streams in Delaware by Maxted (1997). Ongoing work in Vermont suggests that an EIA of up to 10% is tolerated by cohesive stream banks, but the most sensitive streams could only handle up to 3% EIA before degradation was noted (MacRae, personal comm.). Note that the threshold concept is not entirely accurate since the decline in benthic indices in proportion to urbanization occurs along a continuum; however, it provides a basis for the criteria discussed above (Maxted and Shaver, 1999).

As discussed above, the extent of DRC reduction depends upon the cohesion of the stream bank toe stratigraphic unit. The Plasticity Index (PI) of the streambank toe seems to correlate highly with cohesion, so it is possible that bank toe information can be estimated from NRCS Soils Mapping. However, this provides a very rough estimate at best, and field measurements are needed to verify the degree of bank stability of the receiving stream. Depending upon the relative stability of the toe unit, MacRae (1991) recommends DRC targets up to 90%. Note that each stream is different, and a DRC percentage beyond the optimal is projected to actually increase bank erosion due to aggradation. Therefore, site-specific revisions to these targets may thus be required, as discussed in more detail below. Since the relative bank stability of the streams has not been methodically evaluated in Delaware, the literature supports a conservative approach requiring at least the minimum protection of a 50% DRC.

However, nearly all of the available land in the Piedmont physiographic region in Delaware has been developed already, with severe impacts upon the receiving streams. Therefore, overcontrol of the quality storm from new developments in this area would have minimal benefits on already impacted streams. Only in the few watersheds that remain pristine would such an approach be warranted. The vast majority of development now occurs in the Coastal Plain physiographic region, where stream gradients are low enough that bank erosion from urban runoff is not a problem (Dickey, personal communication).

Therefore, Green Technology recommends that the criteria for stream bank protection in the Coastal Plain require that post-development peak flows of 2.0 inches of rainfall match pre-development peak flows. Likewise, there shall be no increase in the peak rate of the two-year runoff event. Stricter criteria using forest cover with 10% EIA for pre-development conditions and a 50% reduction in the peak flows for the 2.0 inch event may be applicable to pristine Piedmont watersheds. Modeling BMPs for selected sites designed for these storm events using continuous simulation models such as PCSWMM may refine this runoff criterion.

4.3 OFFSITE FACTORS IN STREAM BANK PROTECTION

A key factor in selecting required levels of peak flow control is an examination of the status of bank stability in the area affected by development. In alluvial streams where the floodplains have been subject to aggradation and subsequent incision, nickpoints caused by increased flows occur at locations of bed instability. (Nickpoints are the drop in bed elevations where a normal channel falls into an incised channel.) This channel incision alters equilibrium conditions upstream by increasing the local gradient. This results in a large increase in stream energy, causing channel incision to progressively migrate all the way up through the watershed until equilibrium is reestablished (Booth, 1990). Thus, degradation of the "local base level" by channel incision has a most important and far reaching impact (Heede, 1986).

Harvey and Watson (1986) note that there are several stages of stability in this type of alluvial stream. Stage I corresponds to a relatively stable stream section in the headwaters above a nickpoint. Stage II corresponds to the deeply incised channel downstream of the nickpoint. Stage III comprises stream reaches undergoing peak rates of bank erosion due to incision, where the channel rapidly widens. Stage IV occurs where the channel has begun to stabilize, and new floodplains have become established within the limits of the widened channel. Stage V represents a stream reach that has regained dynamic equilibrium, where the original floodplain is now a relict terrace above the new floodplain.

This sequence in the geomorphology of incised channels suggests that stream bank protection measures would be most successful in Stages IV and V (Harvey and Watson, 1986), while nickpoints should be stabilized to preserve Stage I reaches (Harvey and Watson, 1986; Heede, 1986; Booth, 1990). After farming declined in the earlier part of the 20th century in the Delaware Piedmont, most of the streams had attained Stages IV and V by the 1950s. However, due to a new episode of downcutting and bank erosion from urban development over the last few decades, many of these streams are now in Stages II and III. In many of these cases, even the highest level of onsite runoff control will not be adequate, particularly where runoff hydrology has been irretrievably altered by existing development. In the Coastal Plain, bank erosion impacts due to urbanization have been generally less extreme (Dickey, personal comm.). This is due to the lower gradient, as well as the fact that less aggradation has occurred in the first place, and much of the coastal plain remains in agricultural uses.

A further consideration is the role of streamside vegetation. Where streamside vegetation had been removed, highly elevated temperatures and lowered DO levels were observed in Delaware Coastal Plain streams (Maxted and others, 1995). Whipple and others (1981) noted that riparian vegetation increased bank stability in urbanizing creeks. Shields and others (1995) were able to successfully stabilize noncohesive alluvial stream banks by establishing native vegetation. Vegetation decreased bank erosion by up to 80% along a creek in British Columbia (Beeson and Doyle, 1995). Horner and others (1997) noted relatively healthy metrics of benthic diversity in watersheds up to 30% TIA where streams were well buffered with riparian vegetation. Zucker and White (1996) also noted a high correlation between indices of biological integrity and the extent of riparian buffers. Yoder and Miltner (2000) report that habitat and IBI indices are increased in urban areas with intact riparian zones. Horner and others (2000) recommend a continuous riparian buffer of native vegetation as one the best BMPs for streams impacted by urban runoff.

These findings underlie the current thrust in stream restoration efforts with soil bioengineering (Kondolf and Micheli, 1995). Vegetative stabilization is the basis for the potential of RBS and SBR BMPs to provide protection of eroding stream banks. In coordination with onsite controls, RBS and SBR BMPs can provide substantial protection of stream banks and improve streams when compared to existing conditions.

In watersheds where streams are heavily impaired by widespread development, onsite hydrological controls that assume a relatively pristine original condition would be ineffective for new development, and thus represent a wasted expense. In these circumstances, RBS and SBR efforts and structural BMPs, such as regional stormwater facilities and retrofits of existing facilities, would be the most effective approach for restoration. This underlies the need to formulate River Corridor Management Plans (RCMPs) that take into account the status of existing and anticipated watershed development, the destabilization stage of each reach, the susceptibility of streambanks to erosion, and the extent of intact riparian buffers. The cumulative implications of these factors would be used in the RCMP to formulate the appropriate priority for various BMPs, and their target criteria.

In an extremely impaired watershed, a RCMP may permit onsite peak flow controls to use existing average watershed land cover in establishing pre-development conditions, with cost savings to be applied toward offsite BMPs. On the other hand, development in pristine streams with little or no degradation should be subject to the most stringent onsite control requirements, which could likely exceed the 50% DRC reduction, and require a lower EIA in establishing existing conditions. Moderately impaired watersheds could vary between these extremes, depending on the potential for regional facilities and stream bank stability. Where regional offsite facilities are available or projected, onsite control criteria for bank erosion may be relaxed in exchange for pro-rated contributions toward the regional facilities. Where unavailable, the onsite controls would be applied. Absent modifications explicitly incorporated into a RCMP, the minimum required controls would apply to all projects.

4.4 CRITERIA FOR FLOODING EVENTS

Additional criteria include the 10-year storm for conveyance design, and the 100-year storm for flood control. Excluding discharge to tidal waters or situations where regional BMPs are proposed, existing site conditions (without impervious surfaces) represent the targets for the runoff controls.

As 10-year events are generally cyclonic or frontal storms with long interevent intervals, a longer drawdown time of 48 hours is appropriate for storage routing, while avoiding interference from subsequent events. This is important in reducing the flooding potential of synchronized flow peaks from sites with typical 10-year controls. Given that the midbank flood control structure is designed to release its storage volume over 24 hours, the higher control structure would be designed to release its storage volume over the preceding 24-hour period. It is quite possible that the same orifice design for the 2-year peak flow reductions discussed in Section 4.6 would address this requirement in most cases.

Therefore, Green Technology recommends that the design criteria for the 10-year event require that the peak rate be no greater than the pre-development rates under existing conditions (including existing impervious surfaces), and that this volume be released over as long a period as possible. The design criteria recommended for the 100-year event also requires that the peak rate be no greater than the pre-development rates under existing conditions.

CHAPTER 5 URBAN RUNOFF HYDROLOGY

5.1 URBAN RUNOFF MODELS

The hydrological analysis required for urban runoff BMP design must identify the runoff contributions from the various land cover components of a project, as affected by soil characteristics and land cover type. It must also address how such runoff changes in response to rainfall events of differing intensities and precipitation amounts. The hydraulic design elements must be able to realistically calculate the flow path components of runoff, and route runoff through storage structures. It should also be capable of partitioning overland discharge from subsurface infiltration components.

Continuous simulation models such as PCSWMM and HSPF are acknowledged as the most accurate tools for this purpose. Even though these models are now accessible to the desktop, considerable training is required to use them properly, and their extensive data collection, calibration and verification requirements preclude practicality for design of BMPs at the site level. SLAMM (Pitt, 1987) is a simpler continuous model that provides excellent hydrological results in urban watersheds of interest. However, it aggregates many important input parameters for pervious and impervious areas, and has no routing components.

Now that powerful computers are widely available, event-based models have been deemed outdated, inadequate, and even unethical (James, 1994). Simple design storm models are thus considered inappropriate to address receiving water quality issues (Pitt, 2000). However, event based modeling can provide appropriate results when the parameters are properly calibrated by comparison to continuous modeling (Strecker and Reinaga, 2000). These authors noted that the curve number (*CN*) method overestimates runoff peaks in large storms when antecedent moisture conditions were classified as saturated. Using event-based models based upon Hortonian type infiltration equations with decay coefficients, Guo and Adams (1998) and Nnadi and others (1999) report good results compared to continuous simulation modeling. These authors also noted that the *CN* method tended to overestimate runoff in the latter study, apparently due to the influence of antecedent moisture.

The *CN* method has been well documented as an excellent watershed loss model for flooding events (Woodward and others, 2002a). On the other hand, the *CN* method substantially underestimates runoff from small urban watersheds in the small storm events that comprise the great majority of total annual runoff (Pitt, 1987, 2000). Errors in peak flow measurement in these events can range up to 1350 percent (Fennessey and Hawkins, 2002). Indeed, even the authors of the *CN* method have recognized that the curve number for small events (less than 2 inches) must be much higher than the stabilized curve number in order to obtain the observed results (Van Mullem and others, 2002; Hjelmfelt and others, 2002).

Conversely, the *CN* method substantially overestimates runoff peaks (by up to 1000 per cent) from forested watersheds in small storms, since runoff follows shallow subsurface flow pathways with little overland response (Fennessey and others, 2001; Fennessey and Miller, 2002). Since these errors compound each other, using the *CN* method to design BMPs for small storm events where the undeveloped condition is a wooded watershed would result in detention designs that are quite deficient for the events of interest in Green Technology BMP design. Furthermore, even within the same soil *CN* polygon, there can be substantial variations in *CN* depending upon landscape position, with upland *CN*s being less than half the *CN* in concavities where a saturated zone occurs during storm events (Fennessey and Miller, 2002, Fennessey and Hawkins, 2002).

Notwithstanding these limitations, the *CN* method used in TR-20 still remains the method of choice in the design and regulatory community for designing stormwater management facilities. By disaggregating different combinations of land cover and soil type, TR-20 performs well in the larger flooding events of interest in stormwater quantity management, and addresses many of the factors involved in continuous simulation models. TR-55 was subsequently formulated to simplify TR-20 for smaller watersheds. While reasonably close to TR-20 results (within 5% to 10 %), TR-55 is simpler, and used as a basic hydrology program for relatively small, less complex watersheds.

The Delaware Urban Runoff Management Model, or DURMM, has adapted the *CN* method to address the need for a relatively simple, but more accurate, hydrologic modeling approach for small storm events. DURMM hydrology is based upon the Hortonian infiltration equation, as incorporated into the SLAMM model. Along with the pollutant loading elements discussed in Chapter 3, and the pollutant removal routines discussed in Chapters 7 through 11, DURMM is an integrated model for predicting urban runoff volumes, their pollutant loads and their removal by BMPs.

Since TR-20 is already required in Delaware for the design of structural BMPs, DURMM uses the same allocation of discrete polygons defined by land cover and soil group as is used in the *CN* method. Likewise, the determination of the segmental flow pathways used to determine time of concentration (*Tc*) is similar to that used in TR-20. However, DURMM runoff volume computations follow the SLAMM hydrologic equations for small storm event runoff volumes, and they employ a flow-based approach to routing the segmental flow pathways. In this manner, the precision of TR-20 input procedures is complemented by the greater accuracy of the SLAMM computational algorithms and flow-responsive *Tc* computations.

5.2 DURMM MODEL

TR-20 calculates runoff according to the following equation from NRCS (1985):

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \qquad (1)$$

where Q is runoff volume, P is precipitation, S is storage (a term roughly equivalent to accumulated infiltration losses) and Ia is initial abstraction, the initial losses due to interception, depression storage, and evaporation. All units are in terms of depth of runoff and precipitation.

In english units, storage (inches) is related to Curve Number (*CN*) according to the following equation:

$$S = \frac{1000}{CN} - 10 \qquad (2)$$

In TR-20, *Ia* is fixed at 0.2*S*, so runoff relates to precipitation and storage as follows:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad (3)$$

At a given *P*, as *CN* decreases, *S* increases, so *Q* decreases. The more "pervious" the soil cover complex, the greater the storage, which is rarely exceeded in the most pervious areas. As *P* declines toward 0.2*S*, *Q* approaches 0, so no runoff occurs from pervious areas in small rainfall events.

Note also that, while *Ia* is a function of *S*, its effect is to eliminate initial precipitation, even before any *S* is absorbed. The value of *S* is thus independent of *P*, and assumes that no further storage will occur once *P* exceeds *S*. In essence, the soil group/land cover complex is treated as a sponge with a fixed capacity that begins to fill up once *P* exceeds *I*a.

This approach is not at all the behavior of a field scale infiltration model, where infiltration rates will increase with increasing precipitation intensity (Pitt, 1987; Woodward and others, 2002a). Instead, the *CN* method integrates many components of the entire watershed response, including the partial contributing area (PCA) concept (Van Mullem and others, 2002). PCAs are relatively small saturated areas in downslope concavities adjacent to streams, which can be responsible for much of the runoff generation (Kirkby, 1988; Pionke and others, 1988; Gburek, 1900). PCAs are linked to upslope contributory areas by largely subsurface flow pathways during the rainfall event (Pionke and others, 1988). These subsurface flow pathways also directly contribute to the runoff response (NRCS 1985, Hjelmfelt and others, 2002).

As such, the *CN* method was intended to model the entire watershed response, not that of saturation excess flows (which occur very rarely) from each individual contributory land cover complex polygon in upland areas (Van Mullem and others, 2002). Therefore, its use at the small site scale must be viewed cautiously, as noted by Fennessey and associates (Fennessey and Miller, 2002; Fennessey and Hawkins, 2002). Nonetheless, its rainfall/runoff response is considerably more realistic than the Rational Method, and it is already very familiar to the engineering and regulatory community. As such, the *CN* method provides the best available starting point for developing an approach to designing urban runoff BMPs. By providing the modifications discussed below, DURMM attempts to rectify many of the shortcomings of the *CN* approach.

In the agricultural watersheds and larger storm events for which TR-20 was formulated, the value of *Ia* does not substantially affect results, since *P* is usually much greater than 0.20*S*. This value was chosen to best fit the observed data from many watersheds (NRCS, 1985) as a mean between 0.00 and 0.30 (Ponce and Hawkins, 1996). However, for predicting the hydrology of small urban watersheds under smaller storm events, this fixed value for *Ia* in TR-20 has serious shortcomings, and thus TR-20 tends to grossly under predict the hydrological contribution during smaller rainfall events from the lawns and landscaping that comprise urban pervious areas (Pitt, 1987, 2000). This is part of the reason why the curve number in smaller events must be increased to match observed responses (Van Mullem and others, 2002). Indeed, a recent paper by the NRCS researchers suggests that the initial abstraction should closer to 0.05*S*, not to the 0.20*S* originally selected in TR-20 (Woodward and others, 2002b).

For these reasons, equation (3) is only used for runoff events of large magnitude over 5.0 inches (125mm) in DURMM. For the smaller events used in the design of Green Technology BMPs, a different relationship is required to obtain more accurate results.

From extensive comparison of the *CN* method against direct observations of urban runoff events, Pitt (1987, page 199) suggests the following relationship for runoff as a function of *P* (in mm) and *g*, a coefficient based upon *CN*:

$$Q = P - S'(1 - e^{-gP}) \qquad (4)$$

where *S'* is accumulated losses (in mm) after initial abstraction, or *S* - *Ia*. Note that (4) is very similar to the original equation developed by Victor Mockus in formulating the *CN* method (see Mishra and Singh, 1999).

Pitt (1987) provides a table of *g* coefficients regressed to *CN*. The following equation and coefficients were developed to match the values in Pitt's table as a function of *CN*:

$$g = Ae^{B(CN)} + \frac{Ce^{D(CN-B)}}{10{,}000{,}000} \qquad (5)$$

A	B	C	D	E
0.00065	0.0364	155	0.49	80

The first term in (5) is formulated to address the lower *CN*s of pervious areas, while the second term addresses the more direct runoff response of impervious *CN*s. Using these coefficients, equation (5) reproduces the regressed values for coefficient *g* tabulated by Pitt (1987) within 11%.

To get the best fit between (4) and Pitt's (1987) observations for pervious areas, *S'* is set at -0.075, While this negative *Ia* is counterintuitive, it provides the best match to the observations shown in Figure 5-1. Many think *Ia* should be closer to 0.05 for urban areas; for instance see Woodward and others (2002b) who suggest that this value is more appropriate for even rural areas. However, while an *Ia* of 0.05*S* gives a better fit to the observations than 0.20*S*, it is not as good a fit as the negative value used. See also the results presented in Mishra and Singh (1999), in which their model with an *Ia* 0 gave the best fit to observed data for a wide variety of watersheds.

Therefore, there is precedent for the assumption that *S'* would approach *S* for the urban sites of interest in DURMM. When the *CN* is adjusted to correspond to TR-20 values at 125 mm rainfall depths, the value of *S'* used matches observations of runoff from pervious surfaces, as shown in Figure 5-1. The *CN*s allocated for the pervious areas are quite close to the *CN*s used in

TR-20 for lawns in good condition. The curves thus match the observations of the data set as closely as possible, and blend into the TR-20 curves at rainfall depths of 125mm (5 inches).

As shown in Figure 5-1, this curve fit method projects runoff volumes as a function of *CN* that are quite close to runoff observed by Pitt (2000). Note how the runoff volumes at low rainfall depths are much greater than those projected by the *CN* method, while runoff volumes at higher rainfall depths are less than the *CN* method.

This trend in rainfall/runoff relationships follows the observations of rainfall/runoff relationships and declining *CN* values as rainfall amounts increase reported by Pitt (1987), Fennessey and Hawkins (2002), Van Mullem and others (2002), and Mishra and Singh (1999).

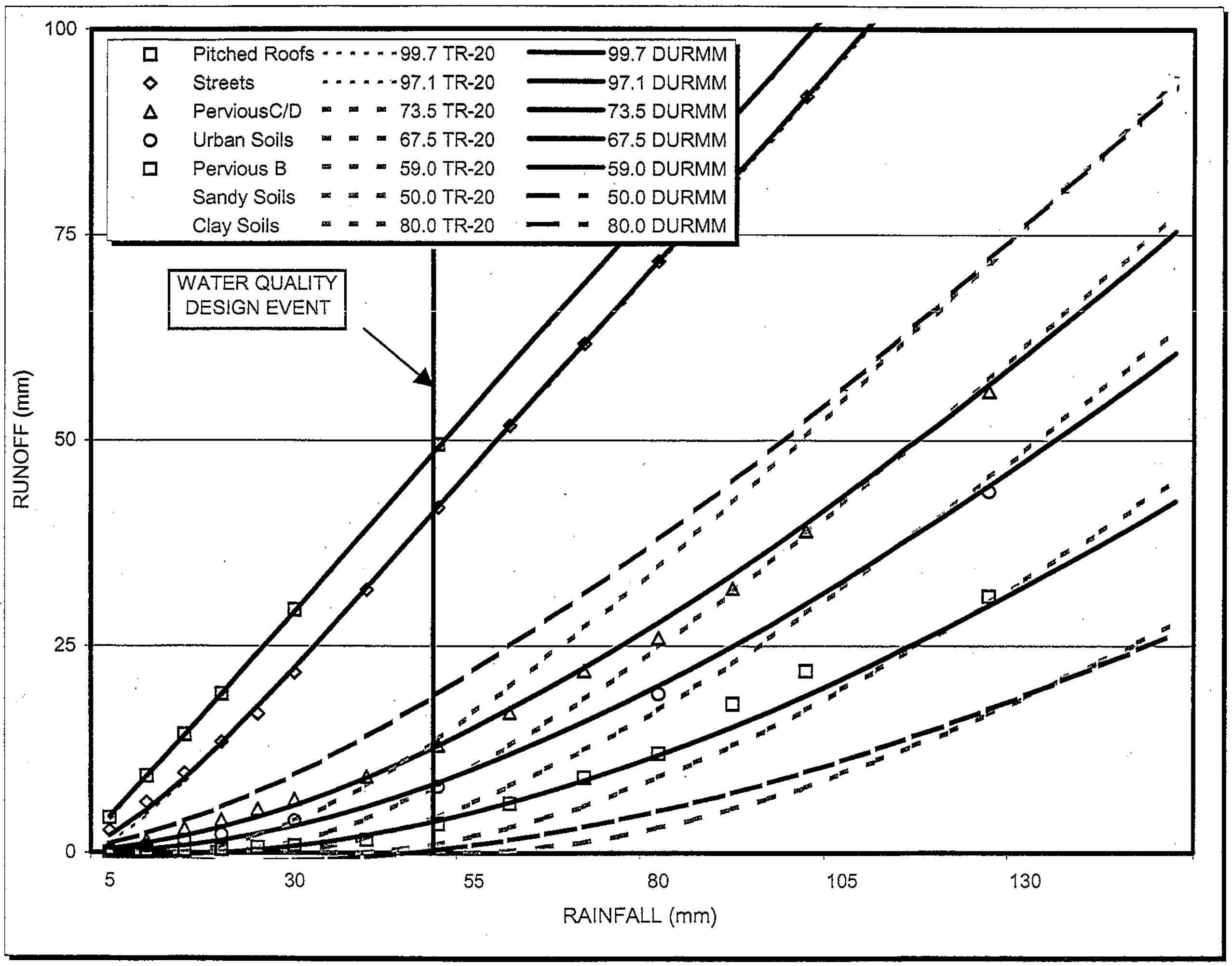

Figure 5-1: TR-20 Runoff, DURMM Runoff, and Observations from Pitt (1987)

5.3 RUNOFF VOLUMES- STORM EVENTS

The runoff predicted from small storms on urban sites using (4) is thus better related to *CN* and *P* than in TR-20. Accuracy in this relationship is essential to realistically model the response of urbanizing area to small precipitation events. At rainfall depths below 60 mm, note how TR-20 runoff volumes (in dotted lines) are much less, or nonexistent, when compared to the curves generated by DURMM routines. Instead, the DURMM curves pass close to the values observed by Pitt at rainfall depths between 25 and 80 mm, the design rainfall amounts for quality and streambank protection routing. To verify that DURMM curves extend over the applicable range of *CN*s for pervious areas, curves are included for sandy soils and clay soils with *CN* values of 50 and 80, respectively. This trend in rainfall/runoff responses follows that generated by reducing *Ia* from 0.20*S* to 0.05*S* as reported by Woodward and others (2002b).

Note the form of equation used in DURMM has the natural log relation used in Hortonian infiltration, and it does not limit infiltration losses as TR-20 does (where *S* is a fixed value). This results in DURMM curves falling below the TR-20 values at higher rainfall depths, as noted by Pitt (1987), Mishra and Singh (1999), and Woodward and others (2002b). This suggests that infiltration rates may increase (and therefore *S* is not a constant value) during more intense rainfall events, as noted by Pitt (1987, 2000).

Taking a conservative approach, DURMM uses the *CN* method equations for the conveyance and flooding events at rainfall depths over 125 mm (5 inches), where the curves between the two methods were selected to meet. Although the crossover threshold in a very pervious watershed occurred at a higher value of 300 mm (Mishra and Singh, 1999), the response of this arid watershed is not applicable to watersheds in the humid east. The effective difference between DURMM and TR-20 is minor at high values of *P*, especially considering that BMP designs evaluate the difference between predevelopment and postdevelopment conditions.

Another very important point raised by Pitt (1987) is that impervious runoff *CN*s are by no means exactly 98, as assumed in TR-20. Impervious surfaces have a certain amount of infiltration and depression storage, depending upon surface roughness and slope, particularly in the case of roofs. Pitched roofs or extensive paving such as parking lots (which permit little infiltration at the edges) have a high *CN* of 99.7, while flat roofs have a *CN* of 98.1, and narrower streets with average roughness have a *CN* of 97.1. Smooth streets have a higher *CN*, and old rough streets have a lower *CN*. When calculating the relative contributions of runoff from these differing types of impervious surfaces, the fine differences between these values are important at low rainfall depths, as shown in Figure 5-1. By eliminating the rounding error introduced in typical TR-20 software packages, DURMM is able to account for these differences. Pitt's values for the differing *CN*s of impervious surfaces are used in the model.

The proper allocation of *CNs* for pervious urban areas is still a matter of some uncertainty. Pitt (1987, 2000) notes that infiltration rates decline over event duration, but increase with rainfall intensity. Compaction has the greatest effect in sandy soils, which would have high rates under natural conditions (Pitt, 2000; Pitt and others, 1999). Clay soils were equally affected by compaction and antecedent moisture. High traffic areas such as playing fields were observed to have infiltration rates even lower than impervious surfaces (Pitt, 1987; 2000; Pitt and others, 1999). A study of lawns on compacted sandy soils in the New Jersey Coastal Plain showed infiltration rates were greatly reduced once bulk density exceeded 1.5

mg/cm^3 (OCSCD, 2001). Originally classified as Hydrologic Soil Group (HSG) A in the uncompacted state, HSGs of the same soils were effectively reduced to C or even D as a result of excessive compaction. The cover condition of these soils would be rated as poor, since plants could not establish an adequate root system.

In contrast to these compaction results, Barros and others (1999) reported that, after a period of adaptation, compacted soils had runoff rates similar to that found under natural conditions. A study of lawn runoff in Wisconsin by Legg and others (1996) noted that there was no runoff from rainfall amounts less than 1 cm, and that rainfall intensity had little effect on infiltration rates. There was substantial variation in runoff rates within individual lawns, and from lawn to lawn. The age of establishment was observed to be a significant variable in determining runoff volumes, with the oldest lawns having the least runoff volumes. Such variations in pervious runoff coefficients were also observed in a study of lawns in Pennsylvania, where infiltration rates were lowest in lawns recently established on compacted areas. Infiltration rates increased as a function of increasing lawn age and soil profile condition, structure and decreasing compaction history (Hamilton and Waddington, 1999).

Well-developed soils with macropores established over time would have better infiltration rates than newly graded sites. This is supported by the findings of Barros and others (1999) that compacted soils returned to a native condition after a period of adaptation over the 9 month time frame of the experimental design. At the end of this period, soils compacted to 90% proctor (nearly suitable for roads), were found to have well developed macropores due to infiltration of applied rainfall. In studies of turfgrass in Wisconsin, Kussow (1994, 1995) reported that runoff volumes from lawns constructed under compaction conditions typically generated by new construction was very low. Appreciable runoff was observed only during the winter when the lawns were frozen.

Recent efforts have examined amending compacted soils by incorporating compost. Pitt and others (1999) note that incorporating compost into the top 10 inches of compacted soils greatly increased infiltration rates, particularly in newer lawns. Runoff responses were commensurate with the increase in infiltration rate. Efforts to improve detention basin performance in New Jersey Coastal Plain using compost have shown substantial increases in infiltration rates (C. Smith, pers. comm.).

Since the underlying design assumptions are directed toward established conditions, the infiltration rates suggested by the older established lawns would be applied in DURMM. Therefore, DURMM presumes that the *CN* values used in TR-20 are applicable to lawns, and that the cover condition is classified as good for typical suburban lawns. For playing fields and urban areas with a high degree of permanent ongoing compaction, the cover condition should be reduced from good to fair to account for compaction that persists over time. In cases of extreme compaction, the cover condition should be classified as poor.

5.4 RUNOFF VOLUMES- ANNUAL DISTRIBUTION

Another approach to evaluate the differing relationships between rainfall and runoff for small events is to compare results from DURMM against that predicted from the *CN* method over the course of a year. Using the annual rainfall distribution set forth in Table 4-1, one can calculate the runoff volume from a given soil cover complex for each quarter inch increment. Multiplied by the percent that each increment comprises of the total rainfall, annual runoff is then derived as the sum of the incremental runoff volumes.

This approach was applied at the landscape scale to the Noxontown Pond watershed in the Delaware Coastal Plain. With an upland area of 5,689 acres, this watershed is largely agricultural, with 62 percent crops, 20 percent forest, 14 percent grass, and an impervious cover of 2.4 percent. Given this setting, pervious runoff, largely from crops, dominates the hydrologic response from the uplands. Noxontown Pond comprises nearly 4 percent of the watershed area, so there is also a substantial volume of direct runoff from the surface of this impoundment.

Upland land cover complex curve numbers were applied from *CN* method, using the values set forth in Table 5-1.

Table 5-1: Land Cover/Soil Group Classifications in Noxontown Pond

NEWTYPE	COVER_	CONDITION_	CURVE NO_A	CURVE NO_B	CURVE NO_C	CURVE NO_D
Agriculture: Cropland	Row Crops, Residue	good	64	75	82	85
Forest: Brush/Shrub	Woods-grass	good	30	58	72	79
Forest: Deciduous	Woods	good	30	55	70	77
Forest: Nursery	Woods-grass	fair	43	65	76	82
Grass: Mixed	Open	fair	49	69	79	84
Grass: Suburban	Open	good	39	61	74	80
Grass: Urban	Open	poor	68	79	86	89
Pastures: Feedlots	Pasture	poor	68	79	86	89
Pastures: Mixed	Pasture	fair	49	69	79	84
Pastures: Open	Pasture	good	39	61	74	80

A GIS was used to determine the total areas of each combination of soil group and land cover, so as to develop the weighted curve number for each land cover type. Note that the cover and condition classification of the crops is rated as good, since the farmers in this area use no-till and cover crops extensively (NCCWRA, 1986). Note also that the grass cover conditions are allocated according to their estimated compaction.

The proportion of rainfall for each quarter inch increment was then applied to the weighted *CN* of each cover type to develop the runoff depth for each rainfall increment. This runoff depth was then multiplied by the percent of rainfall in the increment. Increments were then summed by type to obtain annual runoff depths. Annual runoff depth for each cover type was then multiplied by its surface area to obtain annual runoff volume for each type. Volumes from all types were then summed to obtain the total upland runoff, which was divided by upland area to obtain annual runoff depth.

Using TR-20 routines, the calculated annual runoff depth was only 70 mm (2.77 inches), a value only 7 percent of the annual rainfall of 1,046 mm (41.2 inches). Even applying the worst possible classification to crops (straight row, no residue, poor condition), the runoff depth increased to only 105 mm (4.13 inches). On the other hand, annual runoff using DURMM routines was nearly three times that of the *CN* method, with an annual depth of 189 mm (7.45 inches). Adding the area-normalized runoff depth of 38 mm (1.52 inches) from the pond, the total annual runoff using DURMM routines was computed at 228 mm (8.97 inches).

The USGS has maintained a gauging station for several years on this watershed, so it is possible to obtain a site-specific verification of annual runoff volume. The baseflow component of the runoff hydrographs was determined with the 5 day smoothed minima technique. This is considered the most appropriate method to segregate base flow from runoff (Jordan and others, 1997), particularly in this case, where an impoundment extends stormflow responses. Separation of four years of runoff data resulted in an average annual stormflow volume of 217 mm (8.55 inches). Even though this period is fairly short and rainfall distribution was quite variable, the average rainfall of 1,046 mm is very close to the long-term average of 1,019 mm. This suggests that the value derived from this hydrograph separation is representative of long-term average runoff.

After subtracting direct runoff from the pond, upland runoff by hydrograph separation is computed to be 179 mm (7.05 inches). This value is within 6 percent of that computed by DURMM routines. On the other hand, the *CN* method underestimates this value by over 60 percent. This analysis provides robust support that the routines used in DURMM better replicate actual conditions than the *CN* method for small rainfall events that dominate the annual response.

5.5 IMPERVIOUS DISCONNECTION

Another important factor in determining urban site runoff volumes is the large difference in runoff volumes between pervious and impervious surfaces at a given rainfall depth, as noted in Figure 5-1. Many design manuals and proprietary TR-20 software packages permit averaging the *CN* over both the pervious and impervious surfaces, unless routed as separate subareas during design. However, this approach can lead to substantial errors in runoff volumes, especially during small rainfall events (Panuska and Schilling, 1993; Tsihrintzis and Hamid 1997; Grove and others, 1998).

This simplification has further exacerbated the shortcomings of TR-20 for small storm hydrology. In contrast, DURMM not only has better algorithms for calculating pervious and impervious runoff as a function of rainfall, it calculates runoff volumes from pervious and impervious surfaces as discrete subareas.

It has been recognized for some time that there is a substantial difference in the volume of runoff from impervious source areas that depends upon whether it is conveyed by impervious flow paths (curb and gutters, pipes) versus pervious flow paths (grassed swales). Source areas from which runoff is conveyed by impervious flow paths are defined as connected impervious areas (CIA), as opposed to total impervious area (TIA). Impervious source areas from which runoff is conveyed by pervious flow paths are called disconnected impervious areas (DIA).

A recent detailed study of urban runoff source areas by Lee and Heaney (2003) documented that CIA runoff comprised 72 percent of total annual runoff, even though it was only 36 percent of TIA, and 13 percent of the watershed. The remaining 87 percent of the watershed contributed runoff only when event rainfall exceeded 20 mm. Indeed, the authors of this study noted that the Rational Method was a reliable indicator of runoff volumes in small events only when restricted to the CIA. These authors thus recommended that CIA runoff be explicitly recognized in computing runoff from urban areas.

In contrast to CIA, substantial reductions in runoff volume from DIA source areas have been noted in many studies of the efficiency of filter strips and swales, where pollutant removal efficiencies have been directly correlated with the reductions in runoff volumes (Wanielesta and Yousef, 1993, and many others). This effect of impervious area disconnection has been noted as an important component of Low Impact Development, and has been incorporated into several BMP Manuals, such as the recent Manuals by New Jersey (NJDEP, 2003) and Maryland (MDE, 2000).

By explicitly segregating impervious from pervious areas, DURMM is capable of quantifying the effects of disconnection. To compute the effects of impervious area disconnection, runoff from disconnected impervious areas is allocated as excess precipitation onto the receiving pervious surfaces (Wanielesta and others, 1997, NJDEP, 2003). By entering the area and *CN* of impervious surfaces, and entering the wetted area and *CN* of receiving pervious surfaces, DURMM then calculates the excess precipitation onto, and the resultant runoff volumes from, the receiving wetted pervious surfaces. While runoff from these pervious surfaces will be higher than that from rainfall alone, it can be substantially less than the sum of runoff from the pervious and impervious areas without disconnection.

To account for these effects, DURMM segregates a site into pervious and impervious subareas. The pervious subarea is further subdivided into a natural pervious area, and a graded pervious subarea. The natural area is considered completely undisturbed, so its soil profile and structure must remain intact. As an incentive to leave as much undisturbed area on a site as possible, runoff from natural areas under post-development conditions is computed by TR-20 routines, thus reducing its runoff compared to DURMM routines for small events. While this may not be technically correct for agricultural areas (see Section 5.4 above), it more closely corresponds to the runoff generated from woodlands and abandoned fields (see Fennessey and Miller, 2002). The graded pervious areas use DURMM routines to compute runoff.

Impervious areas are also further segregated into a disconnected impervious subarea, which discharges into the graded pervious area, and a connected impervious subarea that discharges directly into the BMPs via pipes or curb flow. Within the graded pervious subarea, DURMM computes the reduction in runoff volumes from disconnection routines. In this area, the wetted areas would include some of the lawns below downspouts, filter strips below parking lots and the wetted perimeter of swales. Disconnection routines are also applied to the wetted areas of the BMP(s), further reducing the total runoff during the quality event.

DURMM thus explicitly accounts for the reductions in runoff volumes provided by these wetted pervious surfaces. Designs that promote disconnection can reduce runoff volumes for even highly impervious sites by over 50% in the quality event. If the receiving pervious surfaces are very permeable, disconnection can reduce runoff during the quality event by even more. This feature provides a quantitative process-based approach to project the effects of disconnection, which had hitherto been lacking in the literature, let alone in any quantitative design approach.

As the design basis for the impervious area disconnection BMP, disconnection provides the designer with a powerful tool to quantify the benefits of integrating site planning with drainage design. Measures to decrease *CN* by minimizing impervious areas, maximizing natural pervious areas, and increasing afforestation further reduce runoff volumes. In this manner, DURMM provides a powerful tool to quantify the benefits of conservation design, the most fundamental nonstructural BMP.

By using overland conveyance of runoff wherever possible, not only does overland flow reduce volumes (and peak flow rates, as discussed below), it also permits explicit methods for designing BMPs by disconnecting impervious areas and promoting infiltration as an integral part of the design process. Furthermore, there is substantial potential for removal of pollutants when runoff is conveyed through properly designed swales and filter strips. A critical issue is to properly ensure that the receiving pervious surfaces are truly wetted by locating them below flow spreading structures. Otherwise, the wetted area must be constrained to the channel bottom where flows are concentrated.

After accounting for disconnection, the resulting runoff volume is used for generating event hydrographs using TR-55 routines, as discussed below. Once runoff volumes have been calculated for the different source area categories, DURMM computes pollutant mass loads according to the area weighted Event Mean Concentrations (EMCs) of the contributing source areas, as discussed in the DURMM User's Manual.

5.6 TIME OF CONCENTRATION

Time of concentration (*Tc*) determines the peak flow rate for a given runoff volume. *Tc* is usually determined by the segmental method, in which runoff is first conveyed by sheet flow, then by shallow concentrated overland flow, then by channel flow in pipes or streams. In typical usage on small urban sites, these flow paths times decrease according in that order, with sheet flow being the dominant time element, and channel flow usually being very short.

Even though the watershed response normally comprises subsurface flow and runoff from partial contributing areas that are not subject to segmental flow paths (NRCS, 1985), the segmental method is widely utilized. For small urban sites, it seems to be most appropriate, since the other components of runoff are less applicable. On the other hand, under forested pre-development conditions, subsurface flow paths and PCAs often dominate to the runoff response, so the lag method in NRCS (1985) is considered more appropriate (Fennessey and others, 2001).

However, an investigation of the lag equation applied to 1100 events by Folmar and Miller (2000) indicated that the lag equation under-predicts lag in small watersheds, and over-predicts lag in large watersheds, suggesting that lag time varies less as a function of size. Better results could be obtained adjusting the coefficients, and by accounting for the relief and drainage pattern of the watershed. A comparison of the lag method to observed watershed responses for over 50,000 events by Simas and Hawkins (2002) also suggests that the lag equation in NRCS (1985) should be substantially revised. Even so, when revised to better fit the data, the scatter in the watershed responses was extensive.

For these reasons, the approach in DURMM is to use the segmental approach. However, while *Tc* determines the peak rate, the conveyance velocities that determine *Tc* are themselves determined by peak runoff rate. More complex interactions between flow depth, channel shape and vegetative retardance further affect flow velocities, as will be discussed in detail below. However, the TR-55 equation requires a default coefficient to compute shallow concentrated flow conveyance velocities, in which slope is the only variable.

However, comparison of the segmental method to observations by Folmar and Miller (2000) showed that the segmental approach using the TR-55 coefficient for unpaved shallow concentrated flow grossly underestimates the actual lag time (or *Tc*). This is not surprising, since the default *Kv* coefficient of 16.1 used to compute unpaved flow velocities in TR-20 is 80 percent of that applied to paved surfaces. This results in computed flow velocities that are much faster than actually occur in unpaved areas. Since the flow velocities in shallow vegetated swales are typically much less, this would substantially increase travel times closer to that observed.

Sheet flow is defined as unconcentrated flow occurring for the first 100 to 150 feet of the flow path. Topographic features that would concentrate flows define the end of sheet flow. Sheet flow is calculated according to the equation from TR-20 as follows:

$$Tc = \frac{0.007(nL)^{0.8}}{P^{0.5}s^{0.4}} \qquad (6)$$

where n is Manning's Roughness coefficient, L is flow length (feet), and s is slope. Note that P (inches) in (6) is not restricted to the two-year event, as is used in TR-20. Instead, sheet flow *Tc* decreases as P increases. Analysis of the kinematic wave equation that is the basis for (6) shows that as P increases, flow velocity increases, and so *Tc* decreases.

DURMM provides for two consecutive segments of sheet flow to model complex flow paths. When flow velocity from this equation is calculated with the Manning's n value of 0.24 allocated by TR-20 for dense grass, the resulting velocity is greater than that calculated for swale flows under similar slopes and volumes, as discussed in Chapter 10. This analysis thus suggests that the proper value for turf would be around 0.45, as recommended by Engman (1986) from experimental observations of sheet flow. This value is close to the 0.41 used in TR-20 for BermudaGrass, which has a similar blade density to dense turf of suburban lawns. While this issue deserves further investigation, a Manning's n value of 0.24 is allocated to dense turf in the model so as to correspond with the value presently required in Delaware.

At a 2-year rainfall of 3.2 inches, a lawn with a slope of 2 percent for 150 feet would have sheet flow time of nearly 20 minutes. However, in urban sites, the volume of runoff from impervious surfaces in small events is much greater than that from the pervious surfaces. As such, it is thus inappropriate to use pervious sheet flow paths to determine the *Tc*, and an impervious flow path (typically down the most distant driveway) is more realistic. This greatly reduces sheet flow time.

For shallow concentrated flow (or swale flow), DURMM simultaneously solves for peak flows as a function of *Tc*, while solving for *Tc* as a function of peak flows, as affected by the conveyance parameters. TR-55 is used to estimate peak flows, based upon *Tc* and runoff volumes. The equation used in TR-55 for peak flow is:

$$Q_P = q_u AQ / 640 \qquad (7)$$

where Q_P is peak discharge (cfs) , Q is the runoff depth (inches), A is area (acres), and q_u is the unit peak discharge (cfs/mi.^{2}). q_u is defined as follows:

$$\log(q_u) = C_0 + C_1 \log(T_c) + C_2 \log(T_c^2) \qquad (8)$$

with coefficients C_0, C_1, and C_2 defined as a function of *Ia/P* according to the table for Exhibit 4 in Appendix F of TR-55 (NRCS, 1986). Given *S* from the runoff volumes, DURMM calculates *Ia/P* to the nearest hundredth for linear interpolation between the tabular values to obtain the values of coefficients C_0, C_1, and C_2. Substituted into (8), this gives the peak flow for a given *Tc*.

As discussed in Chapter 6, DURMM provides routines that calculate the velocity of swale flow as a function of conveyance channel geometry, vegetative type and flow depth. Using iterative runs at differing flow depths, swale conveyance design is analyzed to develop total discharge and velocity, which provides the total *Tc* when added to sheet flow *Tc*. Flow depths are adjusted until the flow velocity used to generate swale discharge and *Tc* matches the discharge rate computed by TR-55 using the *Tc* derived from the swale flow calculations.

As in the case of sheet flow, this approach results in decreasing *Tc* as *P* increases. Although this relationship was not observed by Simas and Hawkins (2002) in their analysis of many events in large watersheds, there are many components to the runoff response that are not modeled by segmental flow paths, as discussed above. Such components are largely absent in the small urban sites, where well-documented hydraulic principles of channel flow would determine travel time.

As a result of the swale routines in DURMM, the relative contribution of swale flow to total *Tc* becomes greater than that of sheet flow. This approach reduces the typical dominance of *Tc* by often over-estimated, thus unreliable, and generally inapplicable, sheet flow computations. The swale design parameters can also address channel flow as a narrow, deep swale with a smooth surface cover. By generating a different *Tc* for each storm event, as suggested by Guo and Adams (1999b), DURMM thus generates the *Tc* needed for hydrograph generation of peak flows for the bank protection, conveyance and flooding events.

CHAPTER 6 URBAN RUNOFF HYDRAULICS

6.1 OVERLAND FLOW CONVEYANCE

The preceding discussion emphasizes the importance of swale flow parameters in determining *Tc*, and the resulting peak flow rates. Therefore, a key element in the design of nonstructural BMPs is the design of overland conveyance to retard runoff velocities wherever possible. Not only can overland conveyance slow down flow velocities and thus increase *Tc*, it also disconnects impervious areas and provides for infiltration as an integral part of the design process. Furthermore, the literature indicates the potential for substantial removal of TSS when runoff is conveyed through properly designed swales (Horner, 1988; SWPCD, 1992; Wanielesta and Yousef, 1993).

To address this issue, the methods used in DURMM incorporate detailed swale design features as a fundamental part of the model. The methods set forth in "Biofiltration Systems for Storm Runoff Quality Control" by Horner (1988) are complemented by the work of Barfield and associates (Kao and Barfield, 1978) to form the basis of the following discussion. Modifications are proposed that assist in simplifying the design procedure. By using DURMM routines to relate the variables involved, the accuracy of the design process is also refined. The following discussion reviews the hydraulic elements involved in overland flow through swales, which are defined as wide shallow channels where flows are often submerged below the vegetation height.

6.2 SWALE CROSS-SECTION AREA

Under field conditions, a trapezoidal swale cross-section set forth in the plans evolves over time into a parabolic section at the lower depths involved in biofiltration. For depths below 0.5' (generally well above the maximum depth for filtering), DURMM incorporates a function relating top width *w* to depth *d* for a parabolic swale section. Establishing cross-section shape as a function of depth, it is possible to determine cross-sectional area as a function of depth, and substitute this function for the area term in Manning's equation when determining velocity and flow.

The following expression establishes the half-section profile of the swale at depth *d* as a power function of width *w*:

$$d = A(w/2)^B \tag{9}$$

Rearranging to solve for coefficient A at $d = 0.5$ feet,

$$A = 0.5/(w/2)^B \tag{10}$$

Differentiating (9) (where *d* equals *y*, and *w*/2 equals *x*),

$$dy/dx = AB(w/2)^{B-1} \tag{11}$$

Substituting (10) into (11) and rearranging to solve for *B*,

$$B = dy/dx(w) \tag{12}$$

Since slope at a depth of 0.5 feet is the design side slope ss (hor./ver.) of the trapezoidal section, it follows that $dy/dx = 1/ss$, and $w = w_{bottom} + (1.0 \times ss)$, where w_{bottom} is the trapezoidal swale bottom width. Given B, A is then solved from (10).

Integrating (9) gives the area under the half section as follows:

$$A_{under1/2} = \int A(w/2)^B = A(w/2)^{B+1}/(B+1) \tag{13}$$

To obtain swale area, this must be subtracted from the total half area:

$$A_{total1/2} = w/2 \times d = A(w/2)^{B+1} \tag{14}$$

Subtracting (13) from (14), the area of the swale half section is:

$$A_{swale1/2} = A(w/2)^{B+1} \times [1 - 1/(B+1)] = A(w/2)^{B+1} B/(B+1) \tag{15}$$

Multiplying (9) by $w/2$,

$$A(w/2)^{B+1} = wd/2 \tag{16}$$

Substituting (16) into (15), and multiplying by two for the total swale area,

$$A_{swale} = wdB/(B+1) \tag{17}$$

Rearranging (10),

$$w = 2(d/A)^{1/B} \tag{18}$$

Substituting (18) for w in (17) gives the cross-section area of the swale section:

$$A_{swale} = 2B/(B+1) \times A^{-1/B} \times d^{(1+1/B)} \tag{19}$$

With coefficients A and B solved for the design section, it is possible to solve for area as a function of the one variable d.

Figure 6-1 shows how the design swale section compares to the typical parabolic swale and trapezoidal swale sections, based upon a 12 foot bottom width and 4:1 side slopes. Note how the swale section remains close to the trapezoidal section at depths up to 1.0 feet, typically the maximum depth under flooding conditions. The trapezoidal section parameters are used to set the construction layout of the swale, which ends up being very close to the design section in the field.

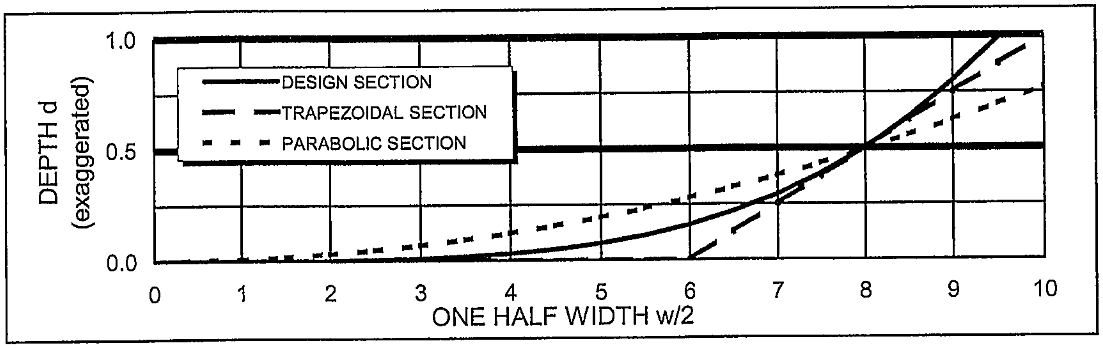

Figure 6-1: Sections for Design, Parabolic and Trapezoidal Cross-Sections

6.3 SWALE HYDRAULIC RADIUS

The wetted perimeter of the swale design function is very close to the width *w* at depths typical for biofiltration. In a trapezoidal section with w_{bottom} of 8 feet and *ss* of 5:1, the difference is less than 1% for depths below 9 inches. This difference would be even less for the design section. Since the term to calculate swale perimeter is somewhat complex, and the area term is much more important in terms of capacity and flow, the approach in this model is to simplify wetted perimeter as being equivalent to top width *w*.

As the exponent for *R* is less than 1.0, the impact of any difference is relatively small. At depths below a foot where biofiltration occurs, this slightly overstates *R*. Therefore, the $R^{0.67}$ term in Manning's equation will increase, overstating velocity and flow. Given that pollutant removal estimates are correlated with increased residence time (at reduced velocities), this introduces a conservative bias to the results. Since the area term is typically at well over one foot, and flow is a function of area squared, precision in the area term is much more important in terms of the overall accuracy of the computations.

Therefore, hydraulic radius *R* is assumed to be equal to *A*/*w*. Given (17), and wetted perimeter $P = w$, hydraulic radius is as follows:

$$R = dB/(B+1) \tag{20}$$

As in the case of cross-section area, it is thus possible to solve for hydraulic radius as a function of the one variable *d*.

6.4 SWALE ROUGHNESS

A key element involved in the design and function of biofiltration swales is the change in Manning's *n* as a function of *VR*, the product of velocity and hydraulic radius. Ree and Palmer (1949, as cited in NRCS, 1992) were the first to investigate this phenomenon empirically, and their work underlies the design basis of grass swales in the Engineering Field Manual (NRCS, 1992) as well as the design of biofiltration swales by Horner (1988). Ree and Palmer found that at a given *VR*, roughness increases as a function of vegetation density and height. Manning's *n* was highest at the lowest values of *VR*, decreasing as *VR* increased. Since Manning's *n* decreases as velocity increases, an increase in flow rate affects flow velocity more than flow depth. Laboratory studies (Kao and Barfield; 1978; Kouwen and Li; 1980, Wu and others, 1999) support the general relationships proposed by Ree and Palmer for emerged flow, when vegetation is overtopped and bent down by the flow.

However, when flow depths are submerged below vegetation height, these researchers noted substantial differences in the relationship between Manning's *n* and *VR*. Under these conditions, Manning's *n* increases in proportion to both slope and square of velocity toward a maximum at the transition to overtopping flow depths (Kuo and Barfield, 1978). Measurements of swale flow in Washington showed that the value of Manning's *n* increased 61 percent from 0.123 at 0.336 fps to 0.198 at 0.472 fps (SWPCD, 1992). When flow is thus submerged, an increase in flow rate affects flow depth more than flow velocity. This counterintuitive relationship was confirmed in measurements of swale flow in Washington, where an increase in flow rate of 55 percent increased velocity by 40 percent, while depth increased by 72 percent (SWPCD, 1992).

In the Horner (1988) method of swale design, Manning's *n* is manually derived by an iterative method comparing an estimated value of *n* and interpolated *VR* from the Ree and Palmer retardance curves, and recalculating *VR* with a different value of *n* if the selected value diverges by more than 5%. This requires several iterations, and it does not address values of Manning's *n* for submerged flow, which is not presented in the NRCS (1992) retardance curves of Ree and Palmer for the vegetation types used in biofiltration swales. As a result, a fixed value of 0.20 was recommended for Manning's *n* under submerged flow conditions (SWPCD). However, this approach results in a larger velocity response to differing flow rates, instead of the relatively small changes in velocity observed.

As an alternative to this method, it is desirable to generate a function relating Manning's *n* to *VR* for both flow regimes. Since a correct roughness value is critical in the design of biofiltration and conveyance swales (SWPCD, 1992), DURMM incorporates this function as part of the design worksheet. This relationship is expressed as a family of coefficients for retardance equations relating Manning's *n* as a power function of *VR*, using separate curves for submerged and emerged flow:

$$\text{for emerged flow, } n = C \times VR^{D}, \quad \text{for submerged flow, } n = E \times VR^{F} \qquad (21)$$

Both equations are solved simultaneously in DURMM, with the lower value of *n* used in subsequent computations. Table 6-1 below shows how these coefficients vary by surface cover:

Table 6-1: Surface Code/Retardance Coefficients

SURFACE TYPE		PAVEMENT	STONE	SHORT GRASS	DENSE GRASS	THICK BRUSH
SURFACE CODE	RETAR-DANCE	1 N/A	2 N/A	3 ("E")	4 ("D")	5 ("C")
C		0.0110	0.0240	0.0355	0.0600	0.0750
D		-0.080	-0.090	-0.360	-0.495	-0.570
E		N/A	N/A	0.800	1.150	1.900
F		N/A	N/A	0.500	0.540	0.600

Accuracy is improved by fitting this function to the range of *VR* below 1.0 involved in bioswale design. It is thus possible to closely approximate retardance curves (well within scaling accuracy) by choosing the appropriate values of *C, D, E* and *F*. Figure 6-2 presents a family of curves based upon these coefficients, such that each curve corresponds to a certain range of *VR* for a specific retardance.

Retardance values are scaled from the curves of Ree and Palmer as published in the Engineering Field Manual, and in Kao and Barfield (1978). Data points from flows in grass filter strips from observations by Abu-Zreig (2001) are included for comparison of these submerged flow values. It should be noted that the curves of Kao and Barfield (1978) do not show such a sharp transition from submerged to emerged flow, and slope also has a substantial effect on Manning's *n* that is not addressed in (21). (Curves for a 2% slope were used in Figure 6-2, since they corresponded most closely to the retardance curves at emerged flow, and bioswales should be designed at the lowest possible grade for best performance.)

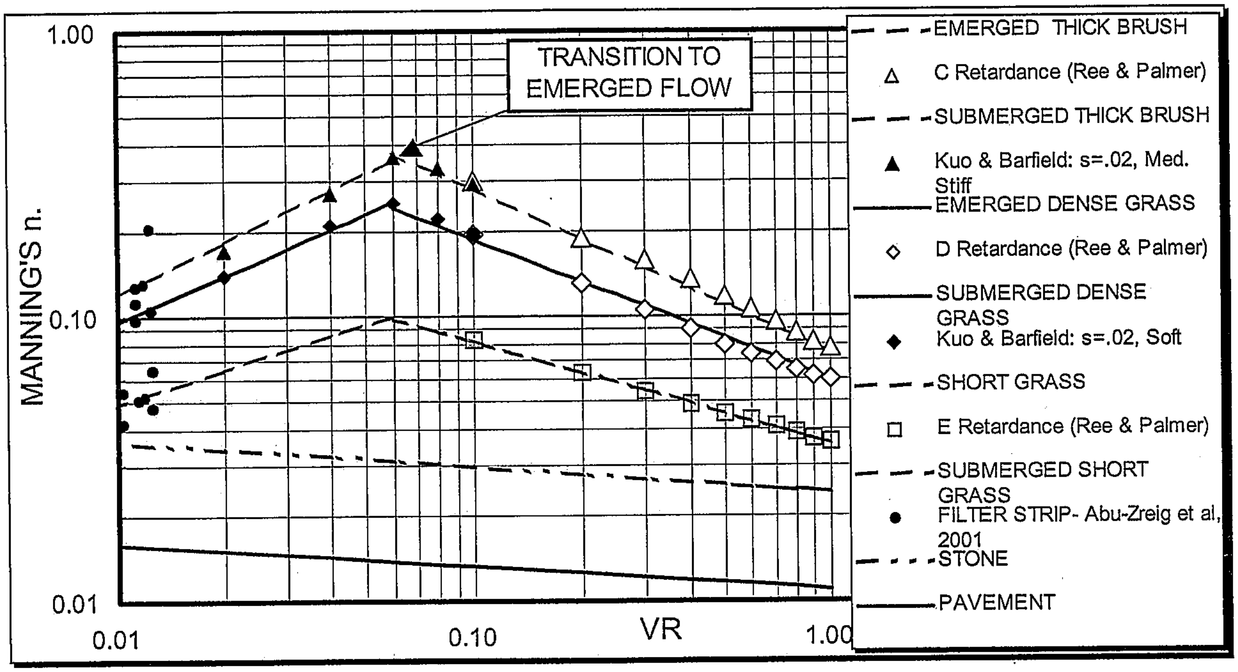

Figure 6-2: Relationship of Manning's *n* to *VR*
Sources: Ree & Palmer (1949), Kao & Barfield (1978) and Abu-Zreig (2001)

Nonetheless, this relationship provides flow velocities for submerged flow that fall within 10% of the flow velocity observations observed by the SWPCD (1992, Table 5-6). This relationship implies that, as flows increase under submerged conditions, flow velocities show minor increases while depth increases. Under emerged conditions, the opposite occurs, as flow depths show minor increases while velocities increase.

The dense grass curve corresponds to Surface Code 4 (or retardance "D") in the range of *VR* values between 0.02 and 1.0 (the Biofiltration Function in Horner's (1988) method). The short grass curve corresponds to Surface Code 3 (or Retardance "E") in values of *VR* between

0.02 and 1.0, representing retardance before grass is well established (the Stability Function). To account for higher retardance due to poor maintenance, the thick brush curve of Surface Code 5 is fitted to values of *VR* between 0.02 and 1.0 for retardance "C" (the Capacity Function). Note that the divergence from the retardance curves is well within 5% at *VR* values below 1.0 typical to biofiltration. Additional curves have been inserted for use on impervious surfaces, using roughness values of 0.11 and 0.24 at *VR* = 1.0 for pavement and stone, respectively. DURMM incorporates these differing surface types in determining flow conditions. Note that Manning's *n* can now be derived as a function of a single variable, depth *d*.

6.5 SWALE FLOW VELOCITY AND DISCHARGE

Given that area, hydraulic radius, and Manning's *n* are all expressed in terms of depth *d*, it is possible to solve for velocity in Manning's equation as a function of depth *d*. Manning's equation for open channel flow is expressed as follows:

$$V = \frac{1.486}{n} \times R^{0.67} \times s^{0.5} \tag{22}$$

where *s* is channel slope. Replacing the terms for *n* and *R* in (20) and (2i) respectively,

$$V = \frac{1.486}{C[VdB/(B+1)]^{D}} \times [dB/(B+1)]^{0.67} \times s^{0.5} \tag{23}$$

Rearranging terms,

$$V = V^{-D} \times \frac{1.486}{C} \times [(B/(B+1)]^{(0.67-D)} \times s^{0.5} \times d^{(0.67-D)} \tag{24}$$

Solving for *V*,

$$V = \left[\frac{1.486}{C} \times [(B/(B+1)]^{(0.67-D)} \times s^{0.5} \times d^{(0.67-D)}\right]^{(1/1+D)} \tag{25}$$

This equation is incorporated into DURMM for swale flow to determine flow velocity as a function of swale shape, surface type and depth of flow, *d*. Swale discharge is then the product of (19) and (25).

When swales are designed for shallow flow depths, the effective roughness values can exceed 0.200, resulting in flow velocities well below one foot per second. This can be particularly important when designing overland flow conveyance BMPs that depend upon residence time to function properly, and it minimizes resuspension of particles in larger events. It is also very important in increasing *Tc* when the dominant flow path is from impervious areas with a rapid sheet flow. Since these swale flow velocities are generally much lower than that allocated by TR-20 in shallow concentrated flow routines, swale flow becomes the controlling factor in determining *Tc*.

The assumptions inherent to equations (19), (20) and (21) introduce minor errors at flow depths above 0.5 feet. With an 0.8 foot depth in an 8 foot wide swale with 5:1 side slopes and a slope of 2%, the area term (19) is reduced by 1%, while hydraulic radius term (20) increases

3.2% and Manning's n term (21) decreases by 4.4%. This results in flows decreasing by 5.9%. However, using an example with a given flow of 28.7 cfs, depth decreases only 1.6% and velocity decreases 2.8%. Given that there is interpolation error and the method is quite precise below depths of 0.5 feet, these minor errors are considered acceptable for conveyance design for wide swales with shallow side slopes. However, it is not recommended for triangular channel sections at deep flow depths, where the errors in (21) can become unacceptably large.

Even when there is no defined channel, shallow concentrated flow is replicated as a swale with a wide bottom and very flat side slopes, as determined from the site plan. As *Tc* is recalculated for each runoff event, this results in decreasing *Tc* as *P* increases. By addressing the implications of swale design in such depth, DURMM provides for overland conveyance computations that are much more representative of actual conditions. Furthermore, these routines permit the designer to explicitly optimize swale design to retard flows and extend *Tc*.

Since pipe flow in the small areas involved in nonstructural BMP design is generally fairly short, and its average velocities are relatively high, the travel time involved is typically negligible. Therefore, DURMM usually omits pipe flow considerations in determining *Tc*. If necessary, long runs of pipe flow can be modeled as swale flow with steep side slopes and a paved surface. The velocities resulting from this approximation are quite close to that computed for pipe flow, so the travel time for a given length is quite similar.

The conveyance module of DURMM described in Appendix A provides estimates for swale response as a function of loading rate, length, width, side slopes, longitudinal slope, and surface cover. Consecutive segments of swale flow are provided to model more complex flow paths. Since the average swale flow is less than peak flow from the outlet, DURMM routines allow for direct input of the proportion of total flow that is conveyed by each swale segment. Design standards, construction specifications and details of biofiltration swales are set forth the Green Technology Standards, Specifications and Details, Appendix B.

6.6 SWALE STORAGE AND DISCHARGE THROUGH CHECK DAMS

Placed at regular intervals, check dams in bioswales can be used to create a series of cascading pools that will provide substantial detention. To estimate the storage volume required to meet predevelopment discharge rates, the following equation from TR-55 (Figure 6-1) provides a useful approximation:

$$V_s / V_r = 0.682 - 1.43_1(q_o / qi) + 1.64(q_o / qi)^2 - 0.804(q_o / qi)^3, \qquad (26)$$

where V_s/V_r is the ratio of storage volume to runoff volume, and q_o / qi is the ratio of peak outflow to peak inflow. The coefficients are applicable to Type II and Type III precipitation. Given pre- and post-development flow rates and runoff volumes derived from the methods discussed above, DURMM computes the estimated storage needed in each event to meet predevelopment flow rates. Note that these are estimated storage volumes, and a comprehensive storage-indication routing method is necessary to confirm the storage volume required according to the outflow routing dynamics.

Since the storage depths in the pools are quite low, it is necessary to obtain stage-area and stage-discharge relationship information at quite small intervals. However, it is difficult to precisely obtain accurate stage/area relationships from construction plans without substantial interpolation errors. When the bioswale with check dam option is used, DURMM precisely calculates the stage-area and stage-discharge relationships for the swale/check dam system.

Given design parameters of longitudinal slope (s), bottom width (w) and side slopes (ss, hor./vert.), the expression for pool surface area at depth h where the pond created by a check dam does not extend up to the next upstream check dam is as follows:

$$A = \frac{h}{s} \times \left[w + (ss \times h) \right] \qquad (27)$$

At higher ponding depths, check dam spacing is less than the calculated pool length, so the length term h/s is replaced by the length between the pools, or total bioswale length L divided by number of pools n. The average width term is also adjusted to account for the depth at the upstream dam location, as determined by slope s and spacing L/n, as below:

$$A = \frac{L}{n} \times \left[w + ss \times (2h - \frac{Ls}{n}) \right] \qquad (28)$$

Using this relationship, DURMM computes the stage-area relationships at intervals of one half the check dam height for entry into the stage-area input fields of a separate hydraulic routing software package. By entering various bioswale lengths, slopes and number of dams, this procedure makes it possible to calculate the increase in volume provided by closer spacing and/or higher check dams.

Equations (27) and (28) are also applicable for calculating storage within terraces with differing side slopes, using the average of the two differing side slopes and a bottom width w of 0 feet. Where terraces are designed to provide biofiltration, they should have a bottom width required for biofiltration. This will normally require excavation into the native soils, resulting in the more uniform side slopes typical to bioswale.

Given stage-area relationships, it is then necessary to route flows through and over the check dams. Complex (and expensive) prefabricated structures are not the optimal arrangement to control flows through check dams, particularly where a very small orifice needed for quality control would be prone to clogging. As a cost-effective alternative, stone-filled gabions can be designed to provide both the required check dam geometry, as well as a mechanism for conveying low flows through the dams. Smaller flow events are routed through the stone, while an orifice and/or weir in the center of the dam is designed to route the larger events. Actual check dam routing is accomplished by entering the dynamics of the check dam design in a separate hydraulic routing software package.

DURMM provides a method to calculate flows through the stone used to construct check dams. Flow through the stone is calculated as a function of stone size, flow depth, width of flow and flow path length. These relationships were initially investigated by McIntyre (1990), who examined gabion weirs as a measure to control flows released from detention basins. McIntyre found that unit width flows could be calculated between these variables according to the following relationship:

$$q = A \times (h^B / L^C), \tag{29}$$

where q is the flow per unit width, h is the ponding depth, and L is the length of flow (up to two feet). A, B and C are coefficients based upon stone size (small, medium and large). Over flow lengths of 1 to 2 feet, (29) provided a very good relation (r^2 = 0.992 to 0.998) for the media evaluated, given the proper values for coefficients A, B and C.

However, the variation in these coefficients does not follow a straightforward relationship to stone size, so (29) cannot be applied for stone media falling outside of the range of stone sizes evaluated. Also, measurements of the flow profile as it passed through the stone by McIntire et al (1991) indicated that entrance losses were significant, so a different form of the denominator of equation (29) was required. Equation (29) was thus modified to address entrance losses, longer flow lengths and different size stone sizes according to the following relationship (McIntyre et al, 1991):

$$q = \frac{h^{1.5}}{(L/D + 2.5 + L^2)^{0.5}}, \tag{30}$$

where D is the average stone diameter in feet. The stone gradation is intended to be relatively uniform in size. Designed for flow paths of up to 6 feet, (30) addresses the range of flow lengths involved in check dam flows. Note that, where the length L is short (less than several feet), changes in stone diameter have a relatively greater effect than where flow paths are longer. Flow path length becomes the dominant factor once it exceeds several feet

The typical gabion width is three feet, so this would be the maximum flow length in most designs. However, where the discharge requirements require a stone size in the range of 1 to 2 inches, such stone will not remain inside a gabion with a mesh of 3 inches. To resolve this, the exposed portion of the gabion can be filled with 4-inch rock, while the smaller stone is placed inside. This reduces the effective flow length to 2.3 feet or so, depending upon the average diameter of the larger rock. Even with the smaller flow length, the smaller stone will result in lower discharge rates. If river rock is used for the exterior stone, this type of gabion dam can be quite attractive.

At low flows, the average flow width through the check dam is less than that at high flows, where weir flow dominates the total flow response in most designs. The geometry of the swale width and side slopes thus becomes the dominant determinants of flow routing at a given stone size. The effective flow width W is calculated as being the bottom width w of the swale, to which is added ponding depth h times swale side slopes ss:

$$W = (ss \times h) + w, \tag{31}$$

DURMM also permits manual entry of a flow path width if a design section narrower than the full width of the swale is needed to control quality events. Since this can be more difficult to construct, this approach is not recommended unless strict release rate criteria are required.

Given the stage-area and stage discharge relationships, it is thus possible to route flows through the bioswale/check dam system. Usually, the combined volume from all ponds can be routed as if they were one pond, discharging through the outflow design for the lowest pond. In check dams where the final outlet is a structure such as a catch basin, it is best to model that pool as a separate pond, since its outflow dynamics can differ substantially from that found in the check dams.

Tailwater will play an important part in routing flows through the check dams, as tailwater retained in the downstream pools will attenuate the flows through the check dams, particularly during conveyance and flooding events. Assuming that the pools tend to fill and discharge together (see below for more discussion), once the flow depth in the downstream pool has backed up onto the stone, increases in flow depth will not increase the head through the stone. For this reason, DURMM provides stage-discharge data through the stone only up to the pool depth, since it will be essentially constant from then on. This data is entered as a special outlet into a separate hydraulic routing package.

For controlling the larger flows, routing software should be used to determine the dynamics of other weirs and orifices. A simple control structure is to install one or several PVC pipes above the quality storm event elevation, sloped so they discharge at grade on the downstream side. Modeled as culverts with entrance losses, this arrangement is not only inexpensive, it also reduces potential scour at the pipe discharge.

During a runoff event, the upper pool fills up first, increasing its effective discharge relative to the lower pools. Since the peak discharge volume will be more than the individual pool can attenuate by itself, it often will overtop the entire dam by several inches. Therefore, the check dam should be depressed by at least 6 inches in the center to ensure flows do not erode the side slopes of the swale. This peak elevation often occurs after peak discharge, since the lower pool is subsequently filled up, thus creating more tailwater and reducing structure efficiency. As the discharge peak passes through the pools, the upper pools also drain more rapidly than the lower pools, reducing their effective head. This relationship tends to distribute the storage volume more rapidly at the beginning, and delay its release at the end of the event.

Tailwater thus varies throughout the event, and until recently, modeling it accurately in a series pool configuration is beyond the capability of most hydraulic routing software packages available. Where precise routing is required, each pool should be modeled individually using software capable of dynamic routing. If routed as individual ponds, these trends result in slightly poorer peak rate reductions of the swale/check dam system when compared to being routed as one larger pond. However, the peak discharge is delayed for longer period, which can be beneficial by desynchronizing peaks from other subareas.

CHAPTER 7 BMP POLLUTANT REMOVAL PROCESSES

7.1 POLLUTANT REDUCTION PROCESSES

Overland flow BMPs remove pollutants from urban runoff through six major pathways: infiltration, filtration, adsorption, immobilization, settlement and transformation. Some, or even all, of these processes can occur simultaneously, depending upon the pollutant involved and the type of BMP. However, there are very few BMP design tools that explicitly account for how these processes function in overland flow BMPs, let alone project the performance to be expected from a particular design.

In wet retention ponds, settling equations have been applied to TSS and particulate nutrient removal (Ferrara and Hildick-Smith, 1982). In wetlands, first order equations are used to project removal of nitrogen (Kadlec and Knight, 1996), and more complex equations have been proposed for removal of phosphorus (Dortch and Gerald, 1995). The complex processes involved in metals removal by wetlands have been investigated in detail by Kallin (1999). Intricate models that simulate these processes have been formulated by several researchers (Kallin, 1999; and sources cited therein).

In the case of vegetated filter strip BMPs, the VFS-MOD model by Munoz-Carpena and others (1992) is an effective tool to predict suspended sediment removal efficiency. A windows-based program, VFS-MOD is an excellent tool to estimate filter strip performance for TSS removal. Recently, Rudra and others (2002a 2002b) have added a phosphorus component, but it is not available yet. While VFS-MOD is quite easy to use, it requires more data entry than typically applied at the typical site development level, and it does not address other pollutants.

The common thread to all process-based models is that the dynamics of pollutant removal reflect the interactions between pollutant loads, hydrologic factors and BMP design parameters. However, such process-based models are too complex for widespread use at the site level. As a result, the approach generally taken by the regulatory community is to assume that a particular BMP imparts specific pollutant reduction efficiencies, assuming certain minimum dimensional and/or loading criteria are provided.

Unlike retention basins however, there is very little data on filtering BMPs (USEPA, 1999). By assuming that the performance from such a limited dataset should be globally allocated to a particular BMP for every case, there is a high likelihood that the "design" pollutant reduction efficiency to be applied will be incorrect. This is analogous to using a broken clock, which can still tell time accurately twice a day. The designer can only hope that the "time" setting is close to what is realistic. Furthermore, this approach provides neither method nor incentive to optimize BMP design for the particular circumstances of each site. Thus, besides being probably inaccurate, this approach thus neither rewards a good design, nor penalizes a bad design.

On the other hand, it is readily apparent that, the better the design is, the better the removal rate will be, and vice versa. To advance the process of BMP design for the regulatory community, the intent in DURMM is to provide a simplified approach that generates results close to that anticipated from process-based models, while requiring much less intensive input data. While DURMM does not attempt to replicate the actual processes involved, it does take into account how the design parameters of overland filtering BMPs respond to their influent pollutant and hydraulic loads.

This approach is far preferable to assuming an invariant pollutant removal efficiency for each BMP. To carry out this approach, the literature on BMP performance has been examined to derive trends that can be represented by relatively simple equations based upon design parameters. Essentially, the concept is to "observe and regress". In this manner, the design of overland filtering BMPs can be better tailored to address the particular situation. Although DURMM is an event-based model, if the relationships derived from this process reflect annual loads and annual flow-weighted concentrations, the results are more likely to better reflect BMP performance through the year.

Unfortunately, there is very little data that actually provides the basis for such relationships. Even though there have been many studies of pollutant removal efficiencies, these studies sample different pollutants, use different sampling methods, have very different input loadings, have many different design parameters, and they present their results as the "average" of the differing pollutant reductions observed in many events. Rare are the studies that investigate annual loads to develop flow-weighted average concentrations, as discussed in Chapter 3.

Depending upon the pollutant measured and the BMP, reported reduction percentages can range over an order of magnitude, and negative reduction percentages are often reported. The issue is further confounded by the predilection for total nitrogen and total phosphorus to be reported as if they were single pollutants, when in fact they each comprise several compounds with very different characteristics affecting their removal by BMPs. This latter aspect is particularly important in overland filtering BMPs. As a result of these confounding factors, published summaries of BMP performance report a considerable variation in the efficiency of BMPs to remove pollutants (CWP, 1997; ASCE, 1999; USEPA, 1999).

The following analysis of BMP performance examines the percentage reduction in effluent EMCs by BMPs, known as the efficiency ratio. Efficiency ratio is not equivalent to the removal percentage expressed as a reduction in pollutant mass loads, as is reported in most studies. This is due to the fact that mass loads represent the product of effluent EMCs and effluent volumes. Since effluent volume losses are considerable, and they are accounted for in the hydrology/hydraulics analysis, it is the EMCs of pollutants remaining in the surface runoff conveyed from the BMPs that become the parameter of interest. Multiplied by the computed runoff volumes leaving the BMP, DURMM then develops the reductions in mass loads during the quality runoff event.

The resultant approach thus follows the sum of loads method presented by Strecker and Quigley (1999). This method is more appropriate for the overland BMPs discussed in this Manual, since infiltration losses can be significant, and efficiency ratios by themselves would understate BMP performance. Given dilution by the receiving stream in any event, total loads are also more accurate in estimating runoff contributions to instream pollutant loads as part of

TMDL requirements. It follows that if reduction targets are met in the 2.0 inch quality event, they will be met in all runoff events that are smaller in volume.

To resolve the factors involved in the reported inconsistency in BMP efficiencies, DURMM examines three factors that control much of the variability in BMP performance. These factors are: 1) input EMC, 2) minimum irreducible EMC, and 3) potential maximum efficiency ratio. Note that input concentrations are independent of BMP design, and minimum irreducible EMC and potential maximum efficiency ratio are generic to the type of BMP. Thus the final value for efficiency ratio is related to effectiveness in the design of the BMP itself. To refine estimates of efficiency ratios, total nitrogen and phosphorus are also segregated into the various species that affect their removal by BMPs.

7.2 IRREDUCIBLE CONCENTRATIONS

It has been recognized for some time that BMPs and wastewater treatment wetlands cannot reduce pollutants below certain thresholds. When an input EMC is very low, such facilities may actually release sequestered nutrients and sediments, resulting in negative efficiency ratios (Strecker and Quigley, 1999). Claytor and Schueler (1996) examined this concept of irreducible (or background) concentrations, and reviewed the existing wastewater wetland and urban runoff BMP literature to obtain the minimum concentrations listed below in Table 7-1:

Table 7-1: Irreducible Concentrations (mg/l) in Urban BMPs

PARAMETER	TSS	TN	TKN	NO3	TP
Urban Runoff BMPs (Schueler, 1996)	20-40	1.9	1.2	0.7	0.15-0.20
Wastewater Wetlands (Kadlec and Knight, 1996)	2-15	1.0-2.5	1.0-2.5	0.05	0.02-0.07

These concentrations will be evaluated in depth for each BMP in the following sections. Irreducible concentrations are obtained from the literature by searching for the lowest repeated outlet EMC reported for a given type of BMP. Given that DURMM provides input values of the EMCs as discussed in Chapter 3, two of the three variables that control performance are thus readily available before even beginning design of a BMP. The remaining element is to determine the potential maximum efficiency.

7.3 MAXIMUM EFFICIENCY RATIOS

Bell and others (1995) measured efficiency ratios as a function of input concentration. As displayed in Figure 7-1, total phosphorus efficiency ratios from a sand filter in Alexandria, VA, showed an increasing trend with input concentration, with the highest efficiency ratio at 87%. It is possible to replicate this relationship by using an asymptotic function in the following form, where efficiency ratio $R\%$ is related to the design maximum efficiency ratio $R_{max}\%$, and the input EMC multiple M of the irreducible concentration:

$$R\% = R_{\max}\%(1 - e^{-K(M-1)}) \quad (32)$$

The lowest effluent concentration reported was 0.065 mg/l, given 35 percent removal at 0.01 mg/l. This suggests that irreducible concentration would be in the range of 0.050 mg/l, shown as the minimum on the upper axis. Using this value for the irreducible concentration, a value of 0.25 for K, and a design maximum efficiency ratio of 90%, the efficiency ratio curve at the higher multiples is within 4 percent of the values reported by Bell and others (1995). The upper x axis displays the input EMC, while the lower x axis displays the multiple *M*. The ordinate displays efficiency ratios, with an asymptote at the maximum of 90%.

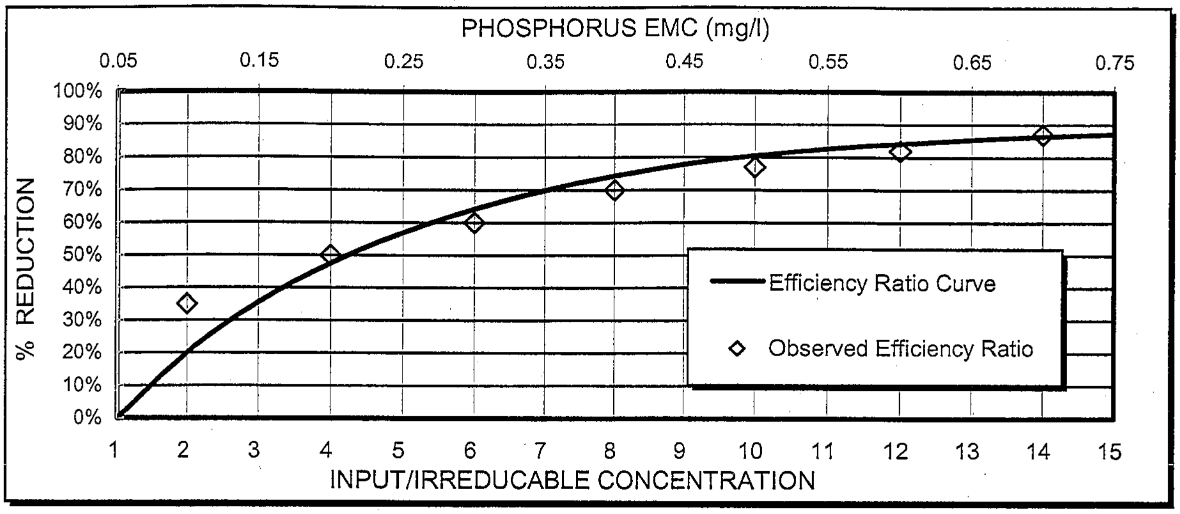

Figure 7-1: Sand Filter Efficiency Ratios as A Function of a Maximum Efficiency Ratios and Input EMC Multiple of the Irreducible Concentration. Source: Bell and others (1995)

Note that this estimated value of the irreducible concentration for TP falls well below the range reported by Claytor and Schueler (1996) for runoff BMPs. In fact, this value is at the low end for wastewater treatment literature. Since (32) underestimates efficiency ratios at multiples below 4, this trend suggests that the minimum may be even lower (which would give higher multiples at these input EMCs). Even though (32) understates the efficiency ratio at low multiples, it is the higher range of multiples that is most relevant to BMP design, so this underestimation has minor effects on the utility of DURMM approach.

Equation (32) thus presents the relationship for projecting likely efficiency ratios as both a function of the irreducible concentration and input EMC. This relationship underlies all further projections of the efficiency ratios as a function of $R_{max}\%$. Note that *(32)* is identical to the standard diffusion equation used in modeling wetland nitrogen removal, when the K value is adjusted to reflect the concentration involved:

$$R\% = (1 - e^{-K(EMC - C\min)}) \tag{33}$$

Unlike the study displayed in Figure 7-1, most of the literature on BMP performance omits the individual event data needed to plot efficiency ratios as a function of input EMC. Therefore, it is difficult to derive the appropriate value for the coefficient K for other BMPs. In the best possible case, a multiple of at least 9 would be required to obtain a maximum removal efficiency of 90%. Using the K value of 0.25 shown in Figure 7-1, it is seen that maximum removal percentage occurs at a multiplier of at least 14. This suggests that appropriate K values can be related to maximum removal efficiencies by assuming that the maximum efficiency ratio occurs at an EMC of roughly 15 times the irreducible concentration. In this case, the value of 0.25, as used in Figure 7-1, is applied as the default value for all BMPs. This value should be refined as more data for individual BMPs becomes available.

Too often, total N or total P efficiency ratios are the only criteria reported, with maximum rates typically below 50%. However, in many overland BMPs, efficiency ratios for soluble fractions will be minimal, while efficiency ratios for the particulate fraction are typically much higher. In contrast to the considerable cycling between these forms that occurs in wet basins and wetlands where the retention time is quite long, there is less cycling between these forms in overland filtering BMPs with relatively short retention times. This is the reason that nutrient loading in Chapter 3 is partitioned into nitrate, ammonia, organic nitrogen, soluble phosphorus, and particulate phosphorus fractions. By segregating nutrients into these fractions, it is possible to differentiate potential reduction of each fraction according to the simplified processes involved in each BMP. Each nutrient fraction will have different irreducible EMCs, with resulting efficiency ratios that vary from minimal to high.

For instance, vegetative filters are relatively ineffective in reducing concentrations of soluble phosphorus, while particulate phosphorus can be effectively filtered. If the relative contributions of the soluble and particulate fractions are available from the loading EMCs, it is possible to obtain better results of the total nutrient reductions. The literature for each BMP is analyzed in the following sections to determine the values for minimum concentrations and maximum efficiency ratios. Note that these values should reflect results supported by other values in the same range. Extreme values that are isolated are not a reliable basis to determine these values.

Maximum efficiency ratio is thus dependent on the pollutant involved, the type of BMP, and how well it is designed to address its loading rates. The reduction processes and the particulars involved in optimizing BMP design are addressed for each type of BMP in the following sections. Relevant relationships of factors such as hydraulic residence time, hydraulic loading ratios, surface/volume ratios, length/width ratios, depth of flow and other parameters are examined for each BMP to develop a quantitative approach to project efficiency ratios for each fraction as set forth in Chapters 9, 10, and 11.

CHAPTER 8 INFILTRATION BMPs

8.1 INFILTRATION BMP POLLUTANT REMOVAL MECHANISMS

The issue of potential leaching of toxic pollutants and nutrients from infiltration BMPs into groundwater has been raised in Chapter 3. While there may be less opportunity for transformation and microbial immobilization processes than in a vegetated surface BMP, filtration processes will reduce pathogens and particulate pollutants, and adsorption processes can sequester soluble pollutants. In essence, the subsoil under the infiltration BMP can function as a sand filter in retaining pollutants in the soil profile. However, since the subsoil profile varies greatly in terms of porosity and cation exchange capacity (CEC, a measure of adsorption potential), the potential for infiltration BMPs to avoid contamination of groundwater is also highly variable.

In sandy soils with a low CEC, the potential for adsorption can be quite low, while infiltration rates would be high. On the other hand, finer soils with a high content of clays will provide excellent filtration and adsorption, but infiltration rates will be lower. Since infiltration BMPs are generally designed for higher rates, it follows that the potential for filtration and adsorption will be relatively low in most infiltration BMPs. For this reason, infiltration BMPs are not recommended for urban "Hot Spots", unless runoff is already well filtered by other BMPs (Parmer and others, 1995). In general, if they are located in mineral soil a sufficient distance from groundwater (at least 20 feet) there appears to be minimal concern for groundwater contamination, even with highly polluted runoff (Livingston, pers. comm.). However, in sandy soils and/or where depth to groundwater is shallow, runoff must be pretreated to ensure that dissolved toxins do not migrate directly into the groundwater.

In terms of nitrogen species, ammonia in urban runoff is either adsorbed to the soil particles, or immediately nitrified into nitrate in the oxic zone under the BMP (Gold and Sims, 2000). Much of the adsorbed ammonia will eventually be nitrified. The extent that biogeochemical processes then sequester nitrate in subsoil is much less than found at the surface, where biomass accumulation can be substantial in the root zone. This results in the soluble species of nitrogen leaving the BMP as nitrate. Since nitrate passes through infiltration BMPs into groundwater without transformation, adsorption or uptake, loading of nitrates generally increases in proportion to the reduction in loading of ammonia.

Where ammonia in the receiving waters is more of a problem than nitrate enrichment, as is occasionally the case for upland streams, this is an effective approach to minimize ammonia loading. However, since nitrates will eventually reach the estuaries and inland bays, this approach can have adverse consequences in the long run. Since urban runoff pollutant loads are segregated into both of the soluble forms, as well as the particulate, DURMM could be used to project event subsurface loading of nitrate and ammonia by assuming that most of the ammonia load is transformed into nitrate. Organic N does not seem to leach into groundwater, so leaching losses of organic N should be minimal. Since these processes are either all or none, there are no process-based approaches to determine the extent of load reductions into groundwater.

Even under very high loads from septic systems, nearly all of the soluble orthophosphate is adsorbed within the soil profile (Gold and Sims, 2000), unless the soils are very sandy. Phosphorus losses would be even less for the particulate forms. However, as they accrue over the long term, some of the particulate fractions will be transformed into soluble forms. Leaching of phosphorus in the groundwater has recently been recognized as a contributor to nutrient loads (Sims and others 1998). However, since these issues are so site specific, subsurface losses cannot be reliably estimated by an event-based approach, so they are not addressed in DURMM.

Therefore, even though infiltration BMPs can substantially reduce surface loading of nutrients and other pollutants through volume reduction, this does not necessarily represent a corresponding reduction in the total nutrient load to streams. This is particularly applicable to nitrate, since there are generally minimal transformations once nitrate passes below the root zone. Even though dissolved nutrients may be out of sight, they may not be out of the regional groundwater system, and thus they represent potential loading from site development.

As a result, groundwater loading from infiltration BMPs could result in significantly less reduction of the amount of soluble nutrients than that reported in the literature, where subsurface losses are rarely addressed. In the absence of a rigorous basis to estimate nutrient and pollutant transformations and adsorption processes in the subsoil, the current approach in DURMM is to ignore these losses.

8.2 SUBSURFACE INFILTRATION BMPs

Infiltration trenches are the preferred subsurface nonstructural infiltration BMP. Dry wells connected to roof downspouts are another common infiltration BMP, but they suffer from an absence of pretreatment. Infiltration basins are structural BMPs that require considerable area and maintenance, and they often fail after several years of operation. DURMM thus focuses on infiltration trenches as the main nonstructural BMPs for site design.

For proper operation, infiltration trenches must be designed to ensure that they do not clog over time. This requires that filtering BMPs are used to provide adequate pretreatment, designed according to the principles set forth in the following chapters. Where the dissolved forms of nutrients, metals and PAHs are a concern due to elevated levels in runoff, pretreatment by these BMPs is essential in any event. As shown in Chapter 3, runoff from roofs can have substantial amounts of TSS, zinc and nutrients; if connected directly to a dry well, the facility is likely to clog, and groundwater loading of nutrients and zinc will occur. While an in-line catch basin can reduce TSS loads, it has minimal effect on nutrients, and it is likely to be poorly maintained, leading to eventual failure. For these reasons, direct connection of downspouts to dry wells is not recommended unless measures can be established that ensure adequate maintenance.

Infiltration trenches thus are the preferred nonstructural subsurface infiltration BMP. Note that volume to surface area relationships and the interaction between width and depth to SHWT favor trenches that are long and narrow over shorter, wide trenches (Guo, 1998). This is another reason to avoid dry wells and other rectangular/circular subsurface infiltration structures. However, note that the preferred geometry can be easily incorporated into linear BMPs such as biofiltration swales and bioretention facilities, which also serve to provide the required pretreatment. This is discussed in more detail in Chapters 10 and 11.

As to the appropriate trench material, crushed stone segregated into one size provides the highest void ratio and least potential for clogging, although a finer material can be used. Coarse filter fabric to prevent the entry of soil fines into the trench should surround the rock at the sides. Recent studies suggest that drainage fabric is not necessary at the top if a smaller stone is used, covered with a sandy loam (Covington, pers. comm.). It is important that the effective pore space of the fabric be quite large, as specified for drainage fabric. Coarse sand should be placed at the bottom to prevent subsidence of the rock into the soil. While clean washed stone is always specified, the reality is that it is rarely provided, so there is a real potential for rock dust to clog the interstitial pores in the adjacent soil matrix and filter fabric. Design standards, construction specifications and details for infiltration trenches are provided in Green Technology Standards, Specifications and Details, Appendix B.

In the case of subsurface infiltration BMPs, there is no reduction in EMCs in runoff that is not infiltrated. Surface runoff loads are only reduced in proportion to the amount of runoff infiltrated during the quality storm event. The inflowing EMC is multiplied by remaining surface runoff volume to determine mass loads leaving the site in surface runoff. The BMP design module of DURMM described in Appendix A provides estimates for infiltration structure performance as a function of loading rate, pollutant levels, length, width, depth, and infiltration rate.

8.3 SURFACE INFILTRATION BMPs

Infiltration has a substantial effect on surface runoff and its pollutant loads by reducing runoff volumes from filter strip, bioswale and bioretention BMPs. As runoff flows from impervious surfaces over the pervious surfaces of these BMPs, its volume can be substantially reduced during the quality storm event. This mechanism is implicitly incorporated into the mass load reduction calculations for filter strip, bioswale and bioretention BMPs as a function of the reductions in runoff volumes due to disconnection. Infiltration also is incorporated into internal site design in terms of impervious area disconnection, as discussed in Chapter 5.

Subsurface leaching losses of nutrients and toxic pollutants are negligible with impervious area disconnection and filtration BMPs, since an intact root zone and soil profile is present to intercept and sequester nutrient and pollutant loads. (See Chapter 3.) Therefore, these infiltration practices are not only very effective; they also have the least potential for groundwater nutrient losses and contamination. Furthermore, they require minimal cost to construct, and the required footprint of surface infiltration BMPs can be incorporated into the overall site layout. Since open areas suitable for surface filtering BMPs are typically provided between buildings and within parking lots in any case, these BMPs do not require excessive loss of potentially useable ground.

For this reason, DURMM goes to some length to determine the extent of runoff reduction in these BMPs, and that resulting from source area disconnection. The input data fields segregate impervious source areas into connected and disconnected categories, as well as receiving pervious areas. Runoff volumes are obtained from both types of impervious areas, to which is applied the impervious disconnection subroutine onto the receiving pervious areas, be they formal BMPs for connected areas or internal landscaping for disconnected areas.

After reducing EMCs in impervious runoff according to equations developed for overland filtering BMPs in the following sections, and multiplying the resulting EMCs by the reduced runoff volumes, mass loads can be substantially reduced. This approach is used for both disconnected internal flow paths and impervious surface runoff directly connected to BMP. The procedures involved in routing these flow paths are described more fully in the DURMM Users Manual, Appendix A.

CHAPTER 9 FILTER STRIP BMPs

9.1 SHEET FLOW FILTRATION RESULTS

Filter Strips represent a class of BMPs in which runoff passes as sheet flow through vegetation. Filtration BMPs provide reductions of pollutant loads through filtration by vegetation and infiltration. While it would seem that the best filter media is turfgrass, recent reports suggest that a dense native meadow stand can be similarly effective. Turf is the obvious choice for many filter strips, since they can be incorporated as lawn areas that happen to be specifically designed to intercept runoff from buildings and parking areas.

However, native warm season grasses have much deeper rooting systems than turf-type cool-season grasses. This greatly promotes infiltration and recharge of runoff into groundwater. There are also several native grasses that form a dense stand at maturity. Studies of a native grasses filter strip by Schultz and others (1993, as referenced by Prairiesource, 1999) show that native grass filter strips have much higher infiltration rates and vegetative uptake than turf grass. Meyer and others, (1995) demonstrated how a hedge of switchgrass as short as only one foot was able to trap nearly 80% of the total sediment load. Sediments settled out in the water ponded over a foot deep behind the grasses, and trap efficiency was higher for the coarse fractions. Since infiltration and runoff volume reduction is a fundamental BMP (see Chapter 5), native warm season grasses are thus preferable for filter strips. However, it is important that the plantings be as dense as possible for the initial 15 feet, where filtering is most important.

Since filter strips are long and narrow, note that the discussion in this Chapter defines width as the dimension direction parallel to the flow, and length as the direction perpendicular to flow. It would seem that flow velocities through filter strips would be slower than flow through swales; however, the discussion on swale roughness in Chapters 6 and 10 suggests that flow velocities are similar in sheet flow and in swales at very low flow depths. Assuming that retention time is thus not the controlling factor, this suggests that grass filter strips provide a greater reduction in particulate fractions than swales since flow is restricted to the densest thatch and blades.

Unfortunately, most of the filter strip literature examines agricultural runoff conditions, where sediment loading rates are typically at least an order of magnitude greater than found in urban runoff. Using rainfall simulators at very high precipitation rates of 200 mm over a day, Dillaha and others (1989) reported TSS EMC reductions from 49% to 93%. Table 9-1 displays results from this site in the Virginia Piedmont for filter strips 4.5 and 9.1 meters wide over slopes of 11%, 16%, and 5% with a cross slope of 4%.

TABLE 9-1: Virginia Piedmont Filter Strip Load and EMC Reductions
Source: Dillaha and others, 1989

SOURCE AREA	WIDTH (m.)		18.3		LENGTH (m.)		5.5	
SLOPE (%)	11		16		5+4		ALL METHODS	
PRECIP. (mm)	200		200		200		200	
LOAD (cu.ft./ft.))	13.95		10.99		11.78		8.25	
RUNOFF (mm.)	70.8		55.8		59.8		186	
RUNOFF (l.)	7126		5616		6019		18761	
INPUT LOADS (kg/ha)								
TSS	3920		8940		2110		14970	
NH4	1.53		4.28		0.76		6.57	
NO3	1.65		1.98		1.22		4.85	
ON	11.73		26.57		6.92		45.22	
TP	4.34		8.41		2.27		15.02	
SP	0.19		0.17		0.10		0.46	
PP	4.15		8.24		2.17		14.56	
OUTPUT LOADS (kg/ha)								
WIDTH (m.)	4.55	9.1	4.55	9.1	4.55	9.2	4.55	9.2
RUNOFF (mm.)	66.1	17.9	55.8	53.2	16	16.6	137.9	87.7
RUNOFF (l.)	8307	2698	7013	8017	2011	2502	17331	13216
TSS	560	100	4,220	2,720	360	150	5,140	2,970
NH4	0.65	0.17	3.56	2.48	0.19	0.11	4.40	2.76
NO3	1.62	0.36	1.85	1.55	0.34	0.34	3.81	2.25
ON	2.91	0.78	12.76	10.11	1.04	1.34	16.71	12.23
TP	1.18	0.32	4.32	2.95	0.35	0.31	5.85	3.58
SP	0.27	0.08	0.17	0.25	0.04	0.04	0.48	0.37
PP	0.91	0.23	4.15	2.70	0.31	0.27	5.37	3.20
INPUT CONCENTRATION (mg/l)								
TSS	5537		16022		3528		8031	
NH4	2.16		7.67		1.27		3.52	
NO3	2.33		3.55		2.04		2.60	
ON	16.57		47.62		11.57		24.26	
TP	6.13		15.07		3.80		8.06	
SP	0.27		0.30		0.17		0.25	
PP	5.86		14.77		3.63		7.81	
OUTPUT CONCENTRATION (mg/l)								
TSS	679	373	6057	3415	1802	604	2985	2262
NH4	0.79	0.63	5.11	3.11	0.95	0.44	2.56	2.10
NO3	1.96	1.34	2.66	1.95	1.70	1.37	2.21	1.71
ON	3.53	2.91	18.31	12.69	5.21	5.39	9.70	9.31
TP	1.43	1.19	6.20	3.70	1.75	1.25	3.40	2.73
SP	0.33	0.30	0.24	0.31	0.20	0.16	0.28	0.28
PP	1.10	0.86	5.96	3.39	1.55	1.09	3.12	2.44
EMC REDUCTION								
TSS %	88%	*93%*	62%	79%	49%	83%	63%	72%
NH4 %	64%	*71%*	33%	59%	25%	65%	28%	40%
NO3 %	16%	*42%*	25%	45%	17%	33%	15%	34%
ON%	79%	*82%*	62%	73%	55%	53%	60%	62%
SP %	-22%	-11%	*20%*	-3%	-20%	4%	-13%	-14%
PP %	81%	*85%*	60%	77%	57%	70%	60%	69%

The extent of reduction was dependent upon filter strip width and slope; the longer and flatter, the better. Runoff decreased substantially in the flatter filter strips as it passed through them, so total load reductions were even greater. Note that the effluent TSS EMCs were still in the range of higher values reported for urban runoff EMCs, since input load EMCs were so high.

Hydraulic loading rate is defined as the runoff volume divided by the length of the filter strip in terms of cubic feet of runoff divided by linear feet of filter strip length normal to the flow. Hydraulic loading rates ranged from 11 to 14 cubic feet of runoff distributed over each foot of filter strip length. These values are at the upper end for typical BMPs, where the loading rate from a 1.5 inch storm over a 60 foot wide contributing impervious area amounts to 7.5 cubic feet per foot. As such, the reported rates represent up to 3 inches of runoff, which is greater than that required for quality storm design.

Similar reductions were noted in the organic N EMCs, while ammonia reductions ranged from 25% to 71%, and nitrate reductions were 16% to 45%. It was thought that nitrate reductions reflect dilution of runoff by rainfall on the filter strip. The authors noted that N transformations in vegetated filters can release sequestered organic N as nitrate, ammonia and, to a lesser extent, dissolved organic N, which was 5% of the total organic N. Ammonia reductions were greater than nitrate, since ammonia is adsorbed onto clay particles, while nitrate is very soluble. Soluble P reductions were minimal or negative, while particulate P reductions ranged from 57% to 85%.

These results support the partitioning of urban runoff into particulate and soluble fractions. Particulate fractions consistently showed high reductions in EMCs, while the soluble fractions -excluding adsorbed ammonia- showed minimal losses, or even increases. Note that good results were obtained with the shorter filter strip of 15 feet. This was confirmed by field observations showing that most of the sediment deposition occurred within the first meter or so. Even though the remaining length of the filter strip had much less accumulation, better results for the 30 foot filter suggest that runoff is further polished as it passes through the strip.

Using a similar experimental design with rainfall events, Parsons and others (1993) conducted a series of observations in the North Carolina Piedmont with filter strips of 5.2% and 6.3% slopes. Table 9-2 displays a summary of some of the storms monitored in this study. Excluding the storm of day 228 (a two year event), hydraulic loading rates are similar to an urban BMP.

As in the case of the results of Dillaha and others (1989), input EMCs of TSS were very high, as were the output EMCs. Although the loading rates were often in the range of urban runoff BMPs, TSS reductions were less. If data from the heavy storm of day 228 are removed from the totals, average reductions of TSS are in the ranges reported by Dillaha and others (1989). However, losses of ammonia and soluble P were much greater, with negative efficiency ratios for these nutrients. (Cells are left blank where a constituent EMC was greater than its combined species, eg., where TKN was less than ammonia.)

TABLE 9-2: North Carolina Piedmont Filter Strip Load and EMC Reductions.
Source: Parsons and others, 1993

SOURCE AREA	WIDTH(m.)		36.6		LENGTH (m.)		4.57							
JULIAN DAY	day 228, 1990		day 333, 1990		day 88, 1991		day 170, 1991		day 226, 1991		day 262, 1991		TOTALS (without day 228, 1990)	
SLOPE (%)	6.3		6.3		6.3		5.2		5.2		6.3			
PRECIP. (mm)	71.6		25.4		0.76?		72.4		41.9		39.4			
LOAD (cu.ft./ft.))	12.93		5.99		3.42		5.21		6.73		5.01			
RUNOFF (mm.)	32.8		15.2		8.7		13.2		17.1		12.7		66.9	
RUNOFF (l.)	5488		2543		1450		2210		2858		2128		11189	
INPUT LOADS (g)														
TSS	45492		8057		5604		25209		3835		3199		45904	
NH4	1.2		1.9		1.9		0.0		0.0		0.0		3.8	
NO3	20.3		1.2		0.4		2.3		2.5		2.9		9.3	
ON	71.0		9.4		3.1		27.1		4.4		3.8		47.8	
SP	3.7		1.2		0.6		0.2		0.6		2.3		4.9	
PP	23.70		2.30		1.50		12.70		1.70		0.80		19.00	
OUTPUT LOADS (g)														
WIIDTH(m.)	4.2	8.4	4.2	8.4	4.2	8.4	4.2	8.4	4.2	8.4	4.2	8.4	4.2	8.4
RUNOFF (mm.)	31.2	31.9	16.1	13.9	10.8	6.5	5.0	8.1	7.5	1.1	6.0	1.8	45.4	31.5
RUNOFF (l.)	5822	6558	3008	2860	2009	1328	930	1673	1392	236	1123	375	8462	6472
TSS	25,490	18,905	2,908	4,616	1,066	2,550	1,137	1,307	170	0	536	336	5,817	8,809
NH4	0.39	0.09	1.90	1.80	4.30	2.00	0.01	0.01	0.01	0.01	0.01	1.80	6.23	3.82
NO3	11.60	10.40	1.60	1.30	2.20	0.60	3.00	3.10	1.40	0.01	5.20	0.01	13.40	5.02
ON	43.21	34.61	10.30	8.30	8.40	0.70	4.09	2.69	1.59	-	2.99	-1.79	27.37	11.69
SP	2.80	2.70	1.80	2.10	2.60	1.40	1.00	2.20	0.90	0.01	3.60	1.10	9.90	5.71
PP	21.20	17.90	2.30	1.20	1.60	-	1.90	0.60	0.30	-	0.40	-0.30	6.50	1.80
INPUT CONCENTRATION (mg/l)														
TSS	8289		3168		3865		11407		1342		1503		4103	
NH4	0.22		0.75		1.31		0.00		0.00		0.01		0.34	
NO3	3.70		0.47		0.28		1.04		0.87		1.36		0.83	
ON	12.94		3.70		2.14		12.26		1.54		1.78		4.27	
SP	0.67		0.47		0.41		0.09		0.21		1.08		0.44	
PP	4.32		0.90		1.03		5.75		0.59		0.38		1.70	
OUTPUT CONCENTRATION (mg/l)														
TSS	4378	2883	967	1614	531	1920	1223	781	122	0	477	896	687	1361
NH4	0.07	*0.01*	0.63	0.63	2.14	1.51	0.01	0.01	0.01	0.04	0.01		0.74	.59
NO3	1.99	1.59	0.53	0.45	1.10	0.45	3.23	1.85	1.01	*0.04*	4.63		1.58	0.78
ON	7.42	5.28	3.42	2.90	4.18	*0.53*	4.40	1.61	1.14	0.00	2.66		3.23	1.81
SP	0.48	0.41	0.60	0.73	1.29	1.05	1.08	1.32	0.65	*0.04*	3.21		1.17	0.88
PP	3.64	2.73	0.76	0.42	0.80	0.00	2.04	0.36	*0.22*	0.00	0.36		0.77	0.28
PERCENT REMOVAL														
TSS	47%	65%	69%	49%	86%	50%	89%	*93%*	91%	100%	68%	40%	60%	61%
NH4	69%	*94%*	15%	16%	-63%	-15%	-138%	-32%	-105%		5%		-53%	-45%
NO3	46%	*57%*	-13%	4%	-297%	-64%	-210%	-78%	-15%	95%	-240%		1%	33%
ON	43%	59%	7%	21%	-96%	75%	64%	*87%*	26%		-50%		31%	52%
SP	29%	*39%*	-27%	-56%	-213%	-155%	-1088	-1353	-208%		-197%		-72%	-42%
PP	16%	37%	15%	54%	23%	*100%*	64%	94%	64%		5%		24%	42%

In the case of ammonia, this can be attributed to the low average input concentration of 0.34 mg/l, as well as the nutrient transformations in the filter strip as discussed above. The losses of soluble P suggest a similar mechanism. These authors also observed the accumulation of sediment in the first meter of the filter strip. However, note that there were minimal, or even negative, reductions of TSS by the longer filter strip, as runoff loads and EMCs from several storms actually seemed to increase from the longer strip. This result of several events suggests that the filter strip cover may have been less than optimal. It should be noted that the total loads decreased due to reductions in runoff volumes.

Recently, Barett and others (1997) reported results from a study of runoff filtration by median strips in Texas. In this study of two medians, roadway loads were measured from road inlets or bridge scuppers adjacent to the median, and median strip EMCs were measured from storm drains that drained the medians. Respective means of TSS, nitrate, TKN, total P and zinc EMCs from the roadways were 157, 0.91, 2.17, 0.55, and 0.347 mg/l for the U.S. 183 site, and 190, 1.27, 2.61, 0.24, and 0.129 mg/l at the Walnut Creek site. Respective means of TSS, nitrate, TKN, total P and zinc EMCs from the median strips were 21, 0.46, 1.46, 0.31, and 0.032 mg/l for the U.S. 183 site, and 29, 0.97, 1.45, 0.16, and 0.032 mg/l at the Walnut Creek site.

The authors noted that flow concentrations did not decrease substantially as flow traveled down the median to the drain, indicating that nearly all of the reduction occurred in the side slopes. The side slopes ranged from 7.5 to 8.2 meters wide, with slopes from 7.2% to 9.4%. According to their estimate of annual loads using the "Simple Method" to estimate runoff volumes, minimal infiltration occurred in the C and D soils in the medians. As a result, filtration was the main process involved in reducing the loads. The authors also observed the accumulation of sediments in the first several feet next to the roadway, with accumulated sediment developing a lip at the edge of the pavement.

While these reductions were substantial, inspection of the experimental design as described in Walsh and others (1997) reveals that these EMCs represent the average (central tendency) of 34 storm events, and a paired analysis was not used. (Several storms monitored for roadway runoff were not monitored for median runoff, and vice versa.) Therefore, these results do not represent a stringent input/output relationship. Furthermore, median flows included flows from other larger pervious areas on the Walnut Creek site, and only half the median of the U.S. 183 site intercepted roadway runoff. At best, the monitored median flow thus includes at least a 50% contribution by overland flow that is not affected by roadway runoff. This predominance by pervious surfaces may explain the increase in fecal coliform observed in the swale runoff.

Even though similar results were obtained for median strip EMCs, it is difficult to ascertain what the EMCs would be at the toe of the median strip itself from this design. Using the median grab samples in the U.S. 183 site as a guide, comparison with the reported EMCs suggests that toeslope TSS EMCs would be roughly twice that reported. To resolve the input/output issue, results from certain storm events are summarized in Table 9-3. To obtain average EMC over the events, EMCs were multiplied by the event runoff volumes, summed and then divided by the sum of event volumes. Table 9-3 provides a better illustration of filter strip efficiencies because it represents the flow-weighted averages from cumulative mass loads.

Using this flow-weighted approach, respective means of TSS, nitrate, TKN, total P and zinc EMCs from the roadways were 335, 1.35, 1.70, 0.35, and 0.268 mg/l for the U.S. 183 site, and 185, 1.27, 1.72, 0.22, and 0.121 mg/l at the Walnut Creek site. Respective means of TSS, nitrate, TKN, total P, and zinc EMCs from the median strips were 13.7, 0.70, 1.04, 0.288, and 0.031 mg/l for the U.S. 183 site, and 17.8, 0.74, 1.04, 0.155, and 0.037 mg/l at the Walnut Creek site. Respective reduction of TSS, nitrate, TKN, total P, and zinc EMCs from the roadways were 96%, 48%, 39%, 17%, and 88% for the U.S. 183 site, and 90%, 42%, 40%, 29%, and 69% at the Walnut Creek site. However, it should be emphasized that these figures represent the upper end of efficiency ratios due to the masking effect of unloaded pervious runoff. Using 5 lanes (60 feet) of roadway, the hydraulic loading rate for a 1.5 inch event would be 7.5 cu. ft. per linear foot of filter length.

Efficiency ratios have also been reported for a filter strip system installed for a ten acre shopping center in Virginia (Yu and others, as cited in CWP, 1994). In this system, 0.4 watershed inches of runoff were diverted to 600 foot long level spreader discharging into a 150 foot wide filter strip with a 6% slope. Efficiency ratios in the upper 75 feet were relatively poor, since vegetative cover was sparse, and gullies had formed. Efficiency ratios at the bottom were similar to that reported by Barrett and others (1998). It is instructive to note that hydraulic loading rates for this filter strip are 24.2 cu. ft. per linear foot of filter length. This loading rate is over 3 times that of the typical median strip situation, and nearly twice of the highest reported by Dillaha and others (1989), so the poor results in the first 75 feet may not be unexpected.

Woodard and Rock (1995) reported the extent of filter strip reduction in TSS and Total P EMCs from homesite construction site runoff in Maine. This study reported substantial reductions of these pollutants over forested filter strip widths of 15 meters, while shorter strips were less effective. The longer filter width needed was attributed to the fairly sparse surface cover of the filter. Slope effects were manifest more in terms of increased loading EMCs than by decreased efficiency ratios. Post-construction loadings were much lower, and the filter strip reductions were proportionately less. Total phosphorus EMCs leaving the filter were fairly high, reflecting the background phosphorus contributions from the forest canopy.

Table 9-3: Input and Output Volumes and EMCs from Highway Median Strips
Source, Barrett and others, 1997

AREA	1200	%IMP.	IMP AREA (sq.m.)		1200	IMP. LENGTH (m)		37.3	WALNUT CREEK SITE					
RV	0.95	100%	PER. AREA		0	IMP WIDTH (m.)		32.2						
STORM	6	15	16	19	20	26	27	28	30	32	31	34	ALL EVENTS	
EMCS FROM ROAD													WEIGHTED AVERAGE	
TSS	257	104	93	26	23	54	98	227	147	256	526	113	185.44	
NO3	0.67	4.74	4.12	1.16	0.45	0.95	1.01	1.21	1.14	1.00		3.37	1.27	
TKN	1.22	3.20	2.14	1.59	3.04	0.81	2.05	1.79	1.73	1.95	1.85	3.00	1.72	
TP	0.33	0.23	0.28	0.48	0.21	0.07	0.16		0.15	0.35	0.39	0.25	0.219	
ZN	0.178	0.110	0.076	0.036	0.024	0.007	0.280	0.085	0.093	0.131	0.280	0.226	0.121	
SWALE OUTPUT														
AREA	104600	%IMP.	IMP AREA (sq.m.)		39352	IMP WIDTH (m)		37	SWALE WIDTH		18	%SWALE		
RV	0.23	38%	PER. AREA		65249	IMP LENGTH (m.)		1055	SWALE AREA		18990	0.29	ALL EVENTS	
EMCS FROM SWALE													WEIGHTED AVERAGE & % REDUCED	
TSS	51	24	41	6	4	17	16	8	14	5	60	13	17.8	90%
NO3	1.07	3.69	2.53	3.49	*0.36*	0.50	1.03	0.51	1.45	0.83	0.01	1.22	0.74	42%
TKN	0.90	2.74	2.11	2.11	0.92	0.69	0.97	0.90	0.98	1.01	1.42	1.30	1.04	40%
TP	0.04	0.18	0.22	0.21	0.19	0.19	0.13		*0.11*	0.16	0.15	0.16	0.155	29%
ZN	0.023	0.003	*0.002*	0.002	0.003	0.003	0.018	0.003	0.044	0.122	0.067	0.147	0.037	69%

AREA (sq.m.)	850	%IMP.	IMP AREA (sq.m.)	850	IMP. WIDTH (m)		19	183 SITE			
RV	0.95	100%	PER. AREA	0	IMP LENGTH (m.)		44.7				
STORM NO.	15	16	19	20	22	25	28	32	33	36	ALL EVENTS
RUNOFF	6800	18480	5940	15260	32320	30600	55180	20490	12360	87389	284819
EMCS FROM ROAD											WEIGHTED AVERAGE
TSS	247	117	31	17	135	81	98	3328	522	48	332.9
NO3	3.29	5.66	2.66	0.8	2.25	0.53	0.55	0.43	1.63	0.94	1.35
TKN	5.92	1.87	2.99	1.20	2.21	0.62	0.89	2.06	0.31	2.18	1.70
TP	0.60	0.35	0.51	0.20	0.39	0.16		0.58	0.69	0.30	0.35
ZN	0.459	0.285	0.279	0.030	0.123	0.126	0.093	0.440	0.690	0.410	0.268
SWALE											
AREA (sq.m.)	13000	%IMP.	IMP AREA	6764	IMP. WIDTH (m)		19	SWALE WIDTH		17.5	%
RV	0.37	52%	PERV. AREA	6236	IMP LENGTH (m.)		356.0	SWALE AREA		6230	100%
EMCS FROM SWALE											WEIGHTED AVERAGE
TSS	38	50	3	5	7	14	7	6	6	19	13.7
NO3	2.71	3.71	0.31	0.20	1.32	*0.20*	0.25	0.41	0.68	0.48	0.70
TKN	1.97	1.73	1.83	1.18	0.90	0.78	0.63	1.33	1.07	1.12	1.04
TP	0.46	0.24	0.35	0.21	0.32	0.43			0.28	0.19	0.29
ZN	0.002	0.003	0.002	0.002	0.002	0.025	0.022	0.070	0.050	0.070	0.031
PER CENT CONCENTRATION REDUCTIONS											
TSS	85%	57%	90%	71%	95%	83%	93%	100%	99%	60%	96%
NO3	18%	34%	88%	75%	41%	62%	55%	5%	58%	49%	48%
TKN	67%	7%	39%	2%	59%	-26%	29%	35%	-246%	48%	39%
TP	23%	31%	31%	-5%	18%	-169%			59%	37%	17%
ZN	100%	99%	99%	93%	98%	80%	76%	84%	93%	83%	88%

9.2 VFS-MOD MODEL

A decade ago, Munoz-Carpena, Parsons and Gilliam (1992) developed the VFS-MOD filter strip model. This model uses the *CN* method to predict runoff, and the Modified Universal Soil Loss Equation (MUSLE) to predict sediment loads from the source areas. Filter strip runoff volume reductions are computed by the Green-Ampt equation, while flow through the strip is based upon a kinematic wave approximation. Sediment reductions are computed according to the procedures developed in the 1970's at the University of Kentucky by the team of Tollner, Barfield and Hayes (See Munoz-Carpena and others (1992) for references). This model explicitly computes the runoff volume and sediment losses as it passes through the strip. It also accounts for the development of the initial wedge of sediment that occurs in the first few feet of the strip discussed above.

The VFS-MOD model was subsequently validated in studies of 27 rainfall events in the North Carolina Piedmont (Munoz-Carpena and others, 1999). These investigators reported that the hydrologic responses, sediment loads and subsequent reductions predicted by VFS-MOD were very close to observations, so long as no channelization occurred. Table 9-4 shows how the filter strip performance closely matched predicted observations, with an average error below 6 percent. Note that most of the load reductions were close to the concentration reductions, suggesting that decreases in runoff volume were not substantial.

Note that the 8.4 meter wide strip was much more effective than the 4.2 meter strip at loads above 7,900 mg/l. However, such loads are extremely high for urban situations. At loads below 2,500 mg/l more typical of urban runoff, removal efficiencies in the 4.2 meter wide strips were quite good. This is in accordance with the results of Barrett and others (1997) displayed in Table 9-3. This further confirms that even narrow filter strips can provide good removal rates for urban runoff.

Table 9-4: Input/Output Loads and EMCs from Filter Strips
Source, Munoz-Carpena and others (1999)

Strip Event	112-92 g4	112-92 r1	151b-92 g4	331a-92 g4	331a-92 g8	024-93 g4
Strip Width (m)	4.2	4.2	4.2	4.2	8.4	4.2
INPUT						
Concentration (mg/l)	1080	750	2440	7930	7930	11470
Sediment Load (g)	287.0	188.9	968.3	5788.0	5788.0	6187.8
OUTPUT						
Runoff Volume (m3)	0.1873	0.1129	0.1905	0.6411	0.5240	0.3687
% Model Error	-10.6%	23.5%	-1.6%	-1.1%	5.3%	12.1%
Sediment Load (g)	30.5	17.9	20.1	2488.0	345.0	639.0
% Model Error	1.3%	9.2%	0.7%	0.4%	19.5%	-3.5%
Concentration (mg/l)	162.8	158.5	105.5	3880.8	658.4	1733.1
Conc. Reduction	84.9%	78.9%	95.7%	51.1%	91.7%	84.9%
Load Reduction	89.4%	90.5%	97.9%	57.0%	94.0%	89.7%

In Canada, Abu-Zreig and others (2001), recently confirmed the validity of the VFS-MOD model, once concentrated flows across the filter strip were explicitly modeled as discrete segments. Coefficients of determination (R^2) for infiltration volume and trap efficiency were 0.95 and 0.90, respectively, and the results were highly significant ($p<0.01$). These results confirm that the VFS-MOD model is an effective method to predict filter strip removal kinetics.

9.3 FILTER STRIP REMOVAL KINETICS

The preceding discussion highlights three factors that affect the performance of filter strip BMPs: filter strip width, slope, and hydraulic loading rate, assuming a uniform turf cover condition. There is an abundant literature demonstrating that filter strip trap efficiency increases as filter strip width increases (Dillaha and others, 1989; and many others), although there are occasional circumstances where sediment concentrations increase as filter strip widths increase (Parsons and others, 1993). The authors attributed this latter finding to the relatively poor cover in the filter strip. It should be noted that most TSS deposition occurs within the first few feet, and trapping efficiencies are statistically identical from 15 to 30 feet (Mendez and others, 1989).

To develop a relationship between filter strip width and trap efficiency, Abu-Zreig (2001) ran VFS-MOD on filter strips of varying widths and slopes. Figure 9-1 displays how predicted trap efficiencies approached the maximum reported removal of 93 percent in filter strip widths of 40 to 50 feet. The hydraulic loading rate was 10.8 cubic feet per foot, a value typical for urban runoff loading rates. However, the input concentration was a fairly high 4,000 mg/l, a value roughly 20 times that expected in urban runoff. Note how the VFS-MOD results generally correspond to the observations of Dillaha and others (1989). A relationship following the asymptotic form of equation (32) is applicable to these results. Excluding hydraulic loading rate adjustments, the form of equation used in DURMM is shown in thicker lines in Figure 9-1.

Abu-Zreig (2001) also presented the trap efficiency for the clay fraction, which has much lower efficiencies than suspended sediment as a whole. This is not surprising, since clays have a much slower settling kinetics for a given filter surface area or detention time. Unlike the exponential decay seen in coarser sediments, the trapping efficiency of clay shows nearly linear removal kinetics. Since adsorbed phosphorus is preferentially bound to the clay fraction, this has implications for particulate phosphorus removal.

A counterintuitive finding of this study is that the effect of slope is much less pronounced, and it is absent if the strip is wide enough. In essence, the effect of increasing slope is to shift the x-intercept to the right, so its effect is more pronounced at lesser widths. This relationship is partially due to the fact that increasing slope increases Manning's roughness value under submerged flow conditions (Kao and Barfield, 1978; Kouwen and Lee, 1980). This finding was confirmed by the observations of Abu-Zreig and others (2001). Since both the numerator and denominator of Manning's equation thus increase simultaneously, flow velocity and filter strip retention time is comparatively unaffected. As a result, it is not surprising that the 18% increase in trap efficiency between 11% and 16% slopes shown in Table 9-1 is much less than the 45% reduction in slope. Therefore, slope effects in filter strip efficiency seem to be fairly minor, and have minimal effect on maximum efficiency ratios.

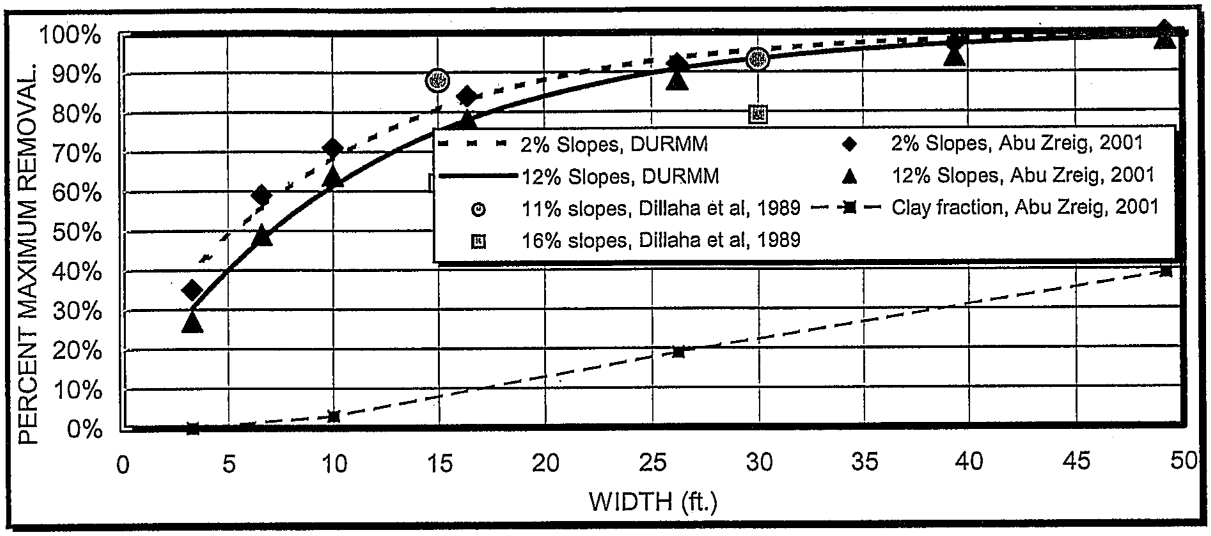

Figure 9-1: Percent Of Maximum Trap Efficiency as a Function of Filter Strip Width and Slope
Sources: Dillaha and others, 1989; Abu-Zreig, 2001

Given the validity of the VFS-MOD model, the following discussion presents model results for a turf grass filter at varying slopes and hydraulic loads. Input parameters were a silty-clay filter strip soil at a moisture deficit of 17.5 percent, suspended sediment with a fine particle distribution (d_{50} = 23 microns), an input concentration of 300 mg/l, and a hydraulic load of 10.5 cubic feet per foot. Results for varying slopes and widths are displayed in Figure 9-2.

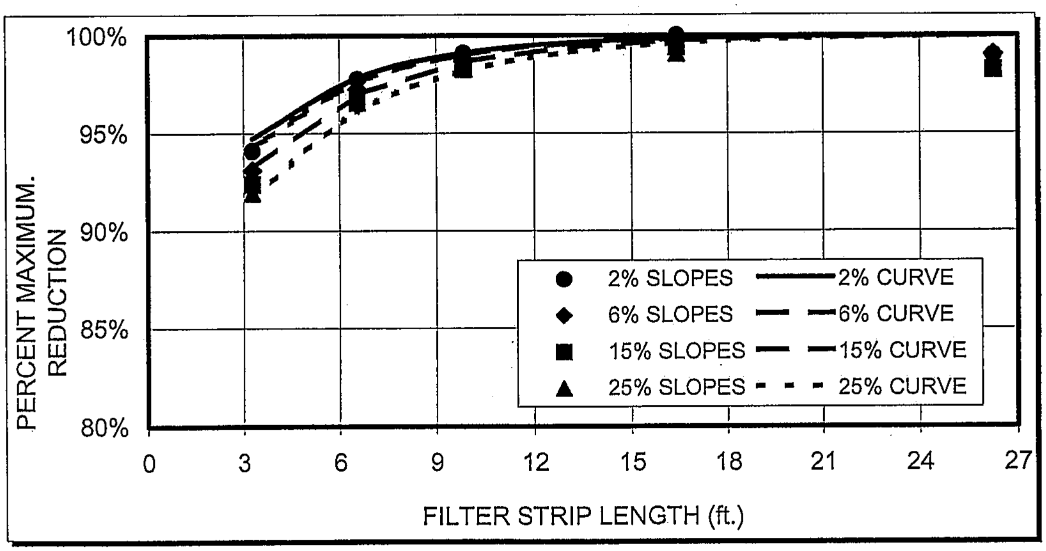

Figure 9-2: Percent Of Maximum Reduction Efficiency as a Function of
Filter Strip Width and Slope

Even under these less than optimal conditions, with silty-clay sediment and tight, moist soils, the computed maximum reduction efficiency was 96.9 percent, a value similar to that reported by Barrett and others (1997). There was very little change in this value (±0.3 percent) for loading rates of 200 and 100 mg/l on a 5 meter strip, so results for these lower loading rates were not computed further.

These model runs further demonstrate the relative lack of sensitivity to slope, even for slopes as high as 25 percent. Note that the scale has been exaggerated to highlight the small differences in removal efficiencies. When removal efficiency is this high, a small difference in removal efficiency represents a large difference in the final output concentration. Therefore, the computation of such subtle differences is important in predicting output loads from filter strips. Note also that the best performance of the filter strip occurs at a width of 16.5 feet (5 meters), and reduction efficiency decreases somewhat at higher widths. This is due to the model computing volumes that decrease more than the loads at the higher width, resulting in higher concentrations.

This effect of differing hydraulic load has not been explicitly reported in the literature, so additional runs of VFS-MOD were preformed to investigate this aspect of filter strip performance. Using the same input parameters as in Figure 9-2 for a 2 percent slope filter strip, Figure 9-3 presents the effects of increasing the hydraulic loads to 21.0 and 31.5 cubic feet per foot of filter strip length:

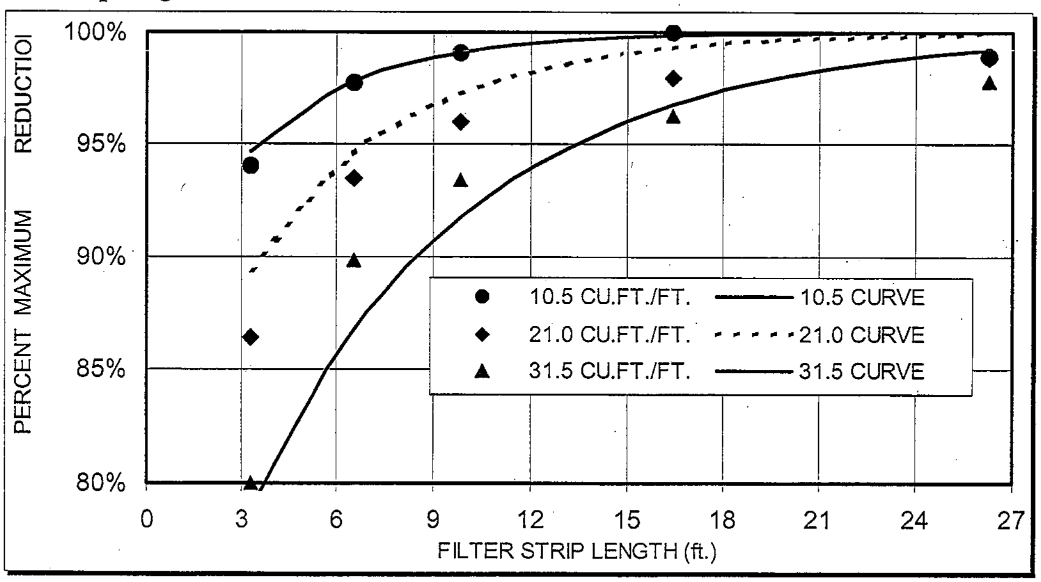

Figure 9-3: Percent Of Maximum Reduction Efficiency as a Function of Filter Strip Width and Hydraulic Load

Over the range of expected loading rates, variations in hydraulic load are seen to have a much greater effect than is projected for slopes. As in the case of slopes, these effects become less prominent as the filter strip gets wider.

Another important variable is the stem density. The results presented above assume that the filter strip cover is in good condition. Obviously, such results would not be expected for filter strips in poor conditions or in winter, when the effective stem density will be less. Since this is the season when most runoff occurs, results for poorer conditions and grasses other than turf need to be examined. In VFS-MOD, bluegrass turf is allocated as having a stem distance (density) of 1.65 cm between stems, while mixed grasses are allocated as having a density of 2.15 cm. (Grasses with higher densities are not recommended in the documentation.) Under the same input parameters as Figure 9-1, the results for the mixed grass stem density are shown below in Figure 9-4. Surprisingly, increasing the stem density by a factor of nearly three to 6.0 did not seem to materially affect performance.

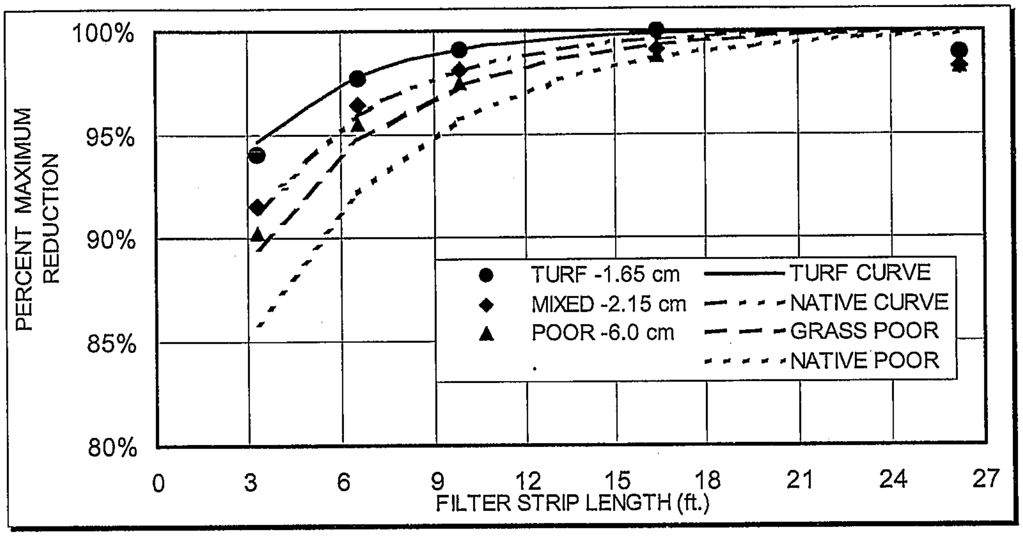

Figure 9-4: Percent Of Maximum Reduction Efficiency as a Function of Filter Strip Width and Stem Density

To replicate these trends with a minimum of computational overhead, DURMM uses the following expression and coefficient values to relate maximum design efficiency ratio, $R_{max}\%$, to maximum possible efficiency ratio $Max\%$, coefficient K, width w, hydraulic loading rate r, slope s, and stem density factor d:

$$R\%_{\max} = Max\% \times \left\{1 - e^{f(K,w,r,s,d)}\right\} \quad (34)$$

where

$$f(K,w,r,s,d) = K \times (A - w) \times (1 - r/B) \times (1 - C/s) \times 1/d \quad (35)$$

Coefficients for (35) are listed below:

K	A	B	C
0.340	-2.30	55	0.65

Stem density factors are listed below:

TURF GOOD	MIXED GOOD	TURF POOR	NATIVE POOR
1.00	1.20	1.30	1.50

The curves derived from equations (34) and (35) are shown in Figures 9-2 through 9-4. While the correspondence to VFS-MOD results is not perfectly matched by these curves, the general trends and range of values are quite satisfactory. In this manner, DURMM provides the capability to rapidly determine the most important elements of filter strip performance in relation to specific site design parameters. It is recommended that poor conditions be applied to the design to account for variability in seasonal growth and potentially poor maintenance. To account for the worst circumstances, an estimated curve for native grasses in poor condition is shown in Figure 9-4.

9.4 MAXIMUM EFFICIENCY RATIOS AND IRREDUCIBLE CONCENTRATIONS

Table 9-5 summarizes data in Tables 9-1, 9-2, and 9-3 relating to the maximum likely efficiency ratios and minimum effluent EMCs for which grass filter strips are capable. The lowest values and highest removal rates are outlined in italics in Tables 9-1 through 9-3. Since the literature is so sparse to refine some of these values, reference is also made to the literature values for biofiltration swales discussed in the next Chapter. Note that the minimum values and maximum removal are intended to be representative values, not the most extreme value observed, which may reflect sampling error.

Based upon the data, particulate and adsorbable soluble species such as TSS, organic N, PP, ammonia and zinc show high potential maximum efficiency ratios in the range of 60% to 97%. Ammonia is subject to both processes of transformation, adsorption and dilution, with projected reductions based upon the Texas results. Although total P showed lower efficiency ratios in Barrett and others (1997), this may be due to the relatively low inflow concentrations. There were high efficiency ratios for particulate P in Dillaha and others (1989) and Parsons and others (1993), where concentrations were much higher. However, recent papers by Rudra and others (2001a, 2001b) suggest that particulate phosphorus removal is likely to be substantially less than TSS removal, since phosphorus is preferentially adsorbed to the finer particles, which have much lower filtration efficiency. Since this depends on both the characteristics of incoming runoff and different filter strip length relationships, no attempt has been made in this version to precisely address the differing reduction kinetics. However, note that the maximum removal percentage for particulate phosphorus is allocated at a conservative 60 percent.

Even though the reduction in nitrate EMCs seems to mostly reflect dilution effects, this is modeled as a reduction in EMCs since DURMM accounts for overall event hydrologic processes, and infiltrated nitrate is largely sequestered in the root zone. However, atmospheric deposition requires that the minimum concentration for nitrate be in the range of 0.15 mg/l, even though reported effluent values are as low as 0.04 mg/l. Since there are many cases where efficiency ratios are negative, the maximum efficiency is projected at 40 percent. The maximum soluble P efficiency ratio is even lower, since biological transformations in the filter strip often exceed input loads due to release of previously sequestered soluble P. Since there is no data on copper removal in the filter strip literature, results from the bioswale analysis in Chapter 10 are projected to apply to filter strips.

To obtain the efficiency ratio for Filter Strip BMPs, maximum reduction percentage *Max%* from Table 9-5 is entered as the first term of the filter strip design equation (34). The rest of the terms in equation (35) are set by the actual design parameters to obtain design efficiency ratio $R_{max}\%$, expressed as a percent of the potential maximum ratio for each pollutant of interest. The minimum EMC values entered as part of the general efficiency equation (32). Actual efficiency ratio *R%* is then depends upon the input concentration entered into (32).

Table 9-5: Maximum Efficiency Ratios and Minimum EMCs for Filter Strips

POLLUTANT	TSS	PP	SP	ON	NH_4	NO_3	Cu	Zn
MAXIMUM REDUCTION %	97%	60%	15%	90%	70%	40%	85%	97%
MINIMUM EMC (mg/l)	5	0.10	0.05	0.40	0.15	0.15	0.002	0.006

The BMP design module of DURMM described in Appendix A provides estimates for filter strip performance as a function of loading rate, pollutant levels, width, slope, and stem density. Design standards, construction specifications and details of the filter strips and level spreader design are set forth the Green Technology Standards, Specifications and Details, Appendix B.

9.5 FILTER STRIP BMPs AND INTEGRATION WITH TERRACE BMPs

An imperative feature in the design in all sheet flow filtration BMPs is the provision of sheet flow conditions. Filter strips are thus best suited for situations where runoff has not been concentrated, as is found from parking lots, driveways, sidewalks, and uncurbed streets. When used as median strips or adjacent to parking lots, the paving itself is an effective level spreading device. However, if filter strips are used after flow has become channelized, their efficiency ratios are not nearly as effective (Dillaha and others, 1989, and many others).

Therefore, an engineered level spreader is necessary to restore sheet flow discharge to the filter strip. Absolutely level surfaces are necessary, and the appropriate structure must be provided. Where runoff from rooftops and curbed roadways is conveyed through pipes, a level spreader is necessary in order to reestablish sheet flow conditions needed for filter strips. See the level spreader details set forth in the Standards, Specifications and Details in Appendix B. Since biofiltration swales are as effective as filter strips in these circumstances, it is questionable whether the potentially less reliable performance of level spreaders is worthwhile, unless there are special circumstances, such as concentrated discharge directly onto a hill slope where a biofiltration swale would require excessive grading.

Filter strips are an integral part of terrace BMPs. In this case, the side slope entering the terrace operates as a filter strip, functioning in a manner analogous to the median filter strips reported in Texas (Barrett and others, 1998). Filtration reductions in the conveyance channel are assumed to be minimal, as flow depths are relatively deep, and runoff is already filtered. Since the side slope provides such substantial filtering, further reductions along the channel would provide minimal additional removal. DURMM thus allocates terrace side slope filtering according to the design parameters in equations (34) and (35).

CHAPTER 10 BIOFILTRATION BMPs

10.1 BIOFILTRATION SWALE RESULTS

Biofiltration swales represent a class of BMPs in which filtering occurs as flow travels along a defined channel. The filter media is usually grass, although ground cover vines, sedges and rushes can also be used. Channel flow velocities along biofiltration swales would seem to be faster than sheet flow through filter strips, since flow depths are greater. However, this may not be the case, as discussed in Section 5.6. Typical flow depths are deeper than sheet flow BMPs, although they should be well below the top of vegetation in properly designed swales. As discussed in Chapter 6, it is very important that vegetation not be submerged, since this causes the vegetation to bend over with the flow, which reduces roughness. Resulting flow velocities will be much greater, and the opportunity for contact filtering is less.

Biofiltration swales are well suited for concentrated flow situations, where runoff has already been collected by piped conveyance systems. However, they are also very effective as a conveyance system in themselves, they can also be designed to provide detention to meet the discharge criteria set forth in Chapter 4. Using detention routing in a similar manner, terraces represent a swale that is surcharged laterally, instead of from a point discharge. As such, terrace BMP removal processes could be considered analogous to that involved in the median filter strips discussed in the previous Chapter.

The literature on biofiltration swale EMC reductions is rather sparse. While there is some data from Florida (Yousef and others, as cited in CWP, 1995), the data is expressed in terms of mass reduction where considerable infiltration had occurred, so removals due to EMC reductions are elusive. The only data set from a swale where infiltration was minimal is presented in a report by the SWPCD (1992). This report measured the responses to 12 storms of a 187 foot long bioswale 5 feet wide with 3:1 side slopes in Seattle, Washington. The authors attempted to ascertain the reduction in swale efficiency if swale retention time was halved by doubling the input flows. However, as discussed in Chapter 6, submerged flow velocities in this swale were essentially constant, regardless of flow rates. As table 5-6 in SWPCD (1992) shows, the cross-sectional areas for the "shorter" runs were identical to the cross-sectional area used in longer runs at similar flow rates, thus the presumed reductions in retention time were based upon a "shorter" effective width. This width was assumed to be half the measured width of 187 feet, since halving the flow was supposed to halve the area. However, the latter is true only in terms of cross-sectional area, not overall wetted area. Table 10-1 presents results from the SWPCD (1992) study.

Flow weighted averages are determined as the sum of products of each event EMC times its flow, divided by cumulative flow of the events measured. Note that Table 10-1 has partitioned total P and the metals into soluble and particulate fractions. Values shown in italics are either below detection limits, flagged as unreliable, or a constituent EMC that had a higher EMC than the total EMC (eg, where dissolved copper EMC was greater than the total copper EMC). These values are excluded from the flow-weighted averages.

Table 10-1: Performance of Biofiltration Swale in Washington State Source: SWPCD, 1992

PARAMETER	INDIVIDUAL STORM EVENT DATA												FLOW WEIGHTED AVERAGES		
DATE	6/20/91	7/15/91	7/24/91	8/9/91	10/24/91	10/31/91	11/17/91	1/16/92	1/23/92	3/27/92	4/17/92	4/29/92	6/20/91 to 1/23/92	3/27/92 to 4/29/92	ALL STORMS
Qavg.(cfs)	0.16	0.02	0.40	0.31	0.21	0.10	0.07	0.03	0.05	0.21	0.25	0.11			
Qpeak(cfs)	0.29	0.12	**0.78**	**1.35**	**0.61**	0.18	0.29	0.09	0.18	**0.49**	**0.65**	**0.56**			
DEPTH(ft.)	0.09	0.01	0.20	0.16	0.11	0.06	0.04	0.02	0.03	0.11	0.13	0.06			
FLOW(cu.ft.)	3168	180	4320	4464	5481	2700	2898	378	1260	2268	3600	2376	2761	916	2758
INPUT CONCENTRATION (mg/l)															
TSS	18	51	180	32	190	19	57	91	51	150	190	150	108	167	113
NO3	0.210	0.640	0.470	0.310	0.230	0.250	0.06	0.590	0.230	0.420	0.031	0.230	0.314	0.195	0.255
SP	0.017	0.043	0.031	0.042	0.088	0.036	0.005	0.005	0.005	0.007	0.022	0.005	0.045	0.013	0.033
PP	0.075	0.287	0.309	0.053	0.142	0.074	0.024	0.115	0.020	0.008	0.138	0.235	0.137	0.130	0.122
Zn-D	0.048	0.150	0.110	0.023	0.021	0.015	0.003	0.003	0.002	*0.042*	0.034	0.019	0.043	0.028	0.035
Zn-P	0.020	0.100	0.100	0.048	0.029	0.023	0.013	0.107	0.094	*0.005*	0.096	0.121	0.053	0.106	0.058
Cu-D	0.002	0.021	0.010	*0.007*	*0.002*	*0.004*	*0.021*	0.002	0.001	0.001	0.002	0.002	0.009	0.002	0.004
Cu-P	0.000	0.010	0.003					0.006	0.005	0.006	0.010	0.012	0.004	0.009	0.006
OUTPUT CONCENTRATION (mg/l)															
TSS	2	12	14	**34**	6	4	4	7	9	**140**	**50**	**150**	13	104	35
NO3	0.210	2.100	1.200	0.570	0.310	0.210	0.060	0.740	0.240	0.490	0.059	0.250	0.544	0.233	0.414
SP	0.014	0.043	0.027	0.088	0.051	0.016	0.005	0.005	0.005	0.005	0.013	0.034	0.042	0.017	0.032
PP	0.056	0.207	0.213	0.022	0.045	0.036	0.010	0.026	0.010	0.000	0.117	0.146	0.075	0.093	0.072
Zn-D	0.010	*0.072*	0.055	*0.058*	0.007	0.002	0.014	0.002	0.001	*0.024*	0.031	0.023	0.021	0.028	0.020
Zn-P	0.022		0.018		0.011	0.004	0.008	0.047	0.012	*0.054*	0.051	0.087	0.016	0.065	0.025
Cu-D	*0.001*	0.012	*0.013*	0.001	*0.004*	*0.005*	*0.006*	0.001	0.001	0.001	0.002	0.002	0.001	0.002	0.002
Cu-P		0.000		0.001				0.002	0.001	0.014	0.007	0.016	0.001	0.012	0.007
EMC REDUCTION															
TSS	89%	76%	92%	-6%	97%	79%	93%	92%	82%	7%	74%	0%	88%	38%	69%
NO3	0%	-228%	-155%	-84%	-35%	16%	0%	-25%	-4%	-17%	-90%	-9%	-73%	-19%	-63%
SP	18%	0%	13%	-110%	42%	56%	0%	0%	0%	29%	41%	-580%	8%	-30%	4%
PP	25%	28%	31%	58%	68%	51%	58%	77%	50%	100%	15%	38%	45%	28%	41%
Zn-D	79%	52%	50%	-152%	67%	87%	-367%	33%	50%	*43%*	9%	-21%	51%	1%	44%
Zn-P	-10%	100%	82%	100%	62%	83%	38%	56%	87%	*-980%*	47%	28%	69%	38%	56%
Cu-D	*50%*	43%	*-30%*	*86%*	*-100%*	*-25%*	*71%*	50%	0%	0%	0%	0%	85%	0%	61%
Cu-P		100%						67%	80%	-133%	30%	-33%	67%	-22%	-21%

Note how the bioswale generally performed well in terms of TSS reductions until the last three storm events. Comparison of the weighted averages displays very different responses from the other storm events in terms of EMC efficiency ratios, some of which can be attributed to reductions in input concentrations. However, even though input TSS EMCs were generally similar, the poor performance of the 3/27/92 and 4/29/92 storms is difficult to explain. The authors noted that the storms in April conveyed substantial silt into the swale, which may have been resuspended during subsequent runoff events.

However, note that poorer results occurred with storms at the higher flow rates, 8/9/91 and 3/27/92. These storms were the worst performing in terms of TSS reduction, suggesting that hydraulic loading rate (or flow depth) has an effect. However, the storms of 7/24/91 and

10/24/91 were among those with the deepest flow depths, yet they obtained excellent reductions. It is possible that these contrary results indicate resuspension of previously deposited fine sediments. It is also important to note that the peak and average flows were quite low in general, especially considering a 14.7 acre watershed with 44% impervious cover. Average flow depths in these storms were quite low, suggesting that performance will be compromised if flow depths get at all close to emergence.

The preceding discussion, however, does not provide any information as to the pertinent details needed to optimize the design of bioswales. The effect of relevant parameters such as hydraulic loading rate (or flow depth) and retention time cannot be determined from the SWPCD (1992) study. However, in a companion study to the median strip results discussed above, Walsh and others (1997) measured EMCs in an artificial flume 30 inches wide and 40 meters long at a slope of 0.44%. It was planted in buffalo grass over a 6 inch topsoil and 3 inch gravel matrix with an underdrain to catch leachate. A "cocktail" of synthetic urban runoff was delivered to the flume, with measurements of EMCs at 0, 10, 20 30, and 40 meters along the flume. Flows were set at depths of 3, 4, 7.5 and 10 cm. Since the latter depth is well above the proper depth for biofiltration, its results have not been displayed in the following discussion.

Figures 10-1 and 10-2 display the reductions in EMCs and efficiency ratios for TSS and Zinc in this experiment. Reductions ranged from 22% to 66% for total P, from 14% to 47% for TKN and minimal or negative for nitrate, as can be expected from previous analysis of filtering literature. There was little correlation with distance or depth of flow for these constituents. While zinc reduction percentages were greater than observed in Seattle, the minimum EMC was in the range of 0.05 mg/l.

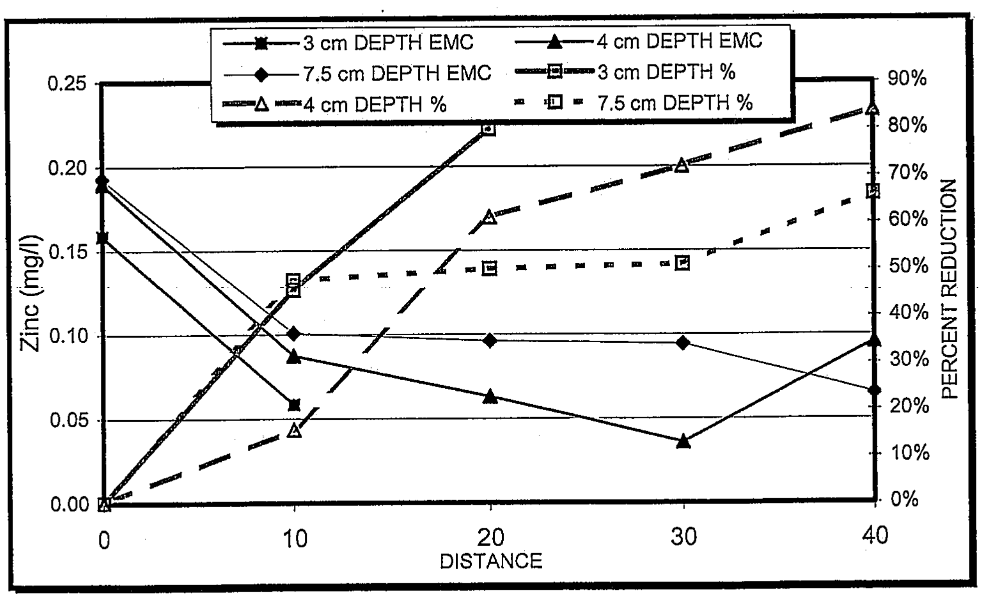

Figure 10-1: Percent Reduction of Zinc as a Function of Distance and Depth
Source: Walsh and others (1997)

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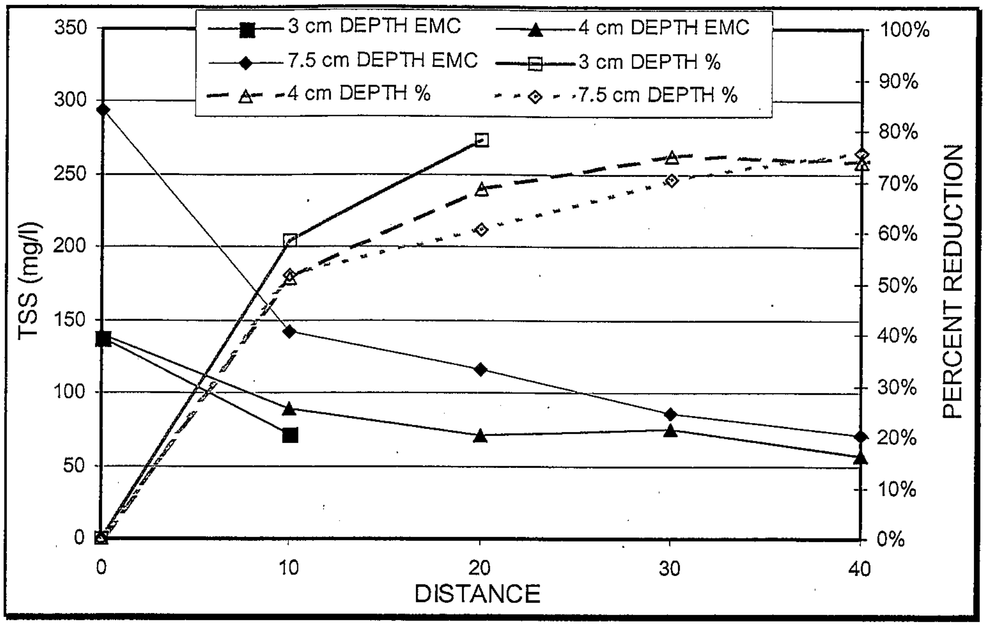

Figure 10-2: Percent Reduction of TSS as a Function of Distance and Depth
Source: Walsh and others (1997)

Note that TSS and Zinc EMCs show a substantial decreasing trend with length. Reductions peaked at around 80% for both these constituents, similar to that observed by the SWPCD (1992) for TSS. Most of the reductions occurred within the first 20 meters, and further losses were relatively minor after 20 meters. Although not shown, the maximum reduction at the 10 cm depth was only 50%, which was reached at 20 meters. Sediment coating on the grass was obvious within the first 3 meters, and still could be observed at 10 meters, but was absent at 20 meters and beyond.

These results suggest that, at the experimental slope of 0.44%, the minimum length for effective TSS and zinc reduction should be at least 20 meters, and preferably 30 meters. Using the geometry of the swale, average flow velocities are calculated between 0.16 and 0.18 ft/sec for the range of flow depths involved. At 30 meters, this suggests a retention time of 9.9 minutes for best results. This value agrees remarkably well with the conclusions of the SWPCD (1992) swale study.

However, note that the final TSS EMC was in the range of 50 to 70 mg/l, roughly ten times the minimum EMC from the Seattle swale. To account for this result, note that the minimum TSS EMC in the leachate was 36 mg/l, with an average of 39 mg/l in the 7.5 cm tests, and 57 mg/l in the 4 cm tests. Given a profile of 6 inches of soil on top of only 3 inches of gravel, a substantial fraction of TSS is lost from the soil profile in every test, so it is not filtered at any length. As such, this fraction seems to be an artifact of the design that may not be applicable to typical biofiltration swale designs for urban runoff.

If the average leachate TSS concentrations are then subtracted from the input and effluent TSS concentrations for the results of the 4 and 7.5 cm tests, the resulting concentrations and efficiency ratios are remarkably similar to that observed in filter strips and in the SWPCD swale.

Figure 10-3 plots the resulting EMCs and reductions as a function of length and retention time. Note that maximum efficiency ratios exceed 90%, and minimum EMCs are 18 and 33 mg/l for the 4 and 7.5 cm tests, respectively. These values are more in line with the results in the SWPCD (1992) swale.

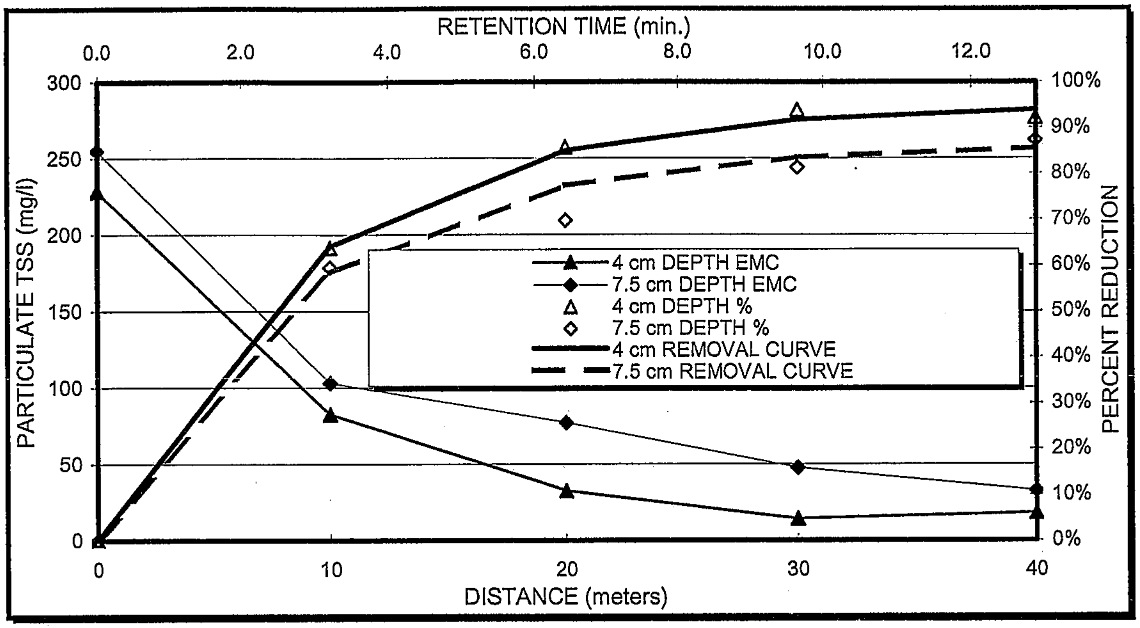

Figure 10-3: TSS EMCs and Reductions as a Function of Distance, Retention Time, and Flow Depth. Data adjusted from Walsh and others (1997)

10.2 BIOFILTRATION SWALE KINETICS

These results show a clear trend for a reduction in efficiency and increase in the minimum concentration with increasing depth of flow, although the minimum EMCs begin to converge by 40 meters. At depths up to 7.5 cm, Equation (36) reproduces these results for efficiency ratio $R_{max}\%$ as a function of retention time T and depth d (in feet):

$$R_{\max}\% = MAX\% \times (1 - e^{-KT}) \times (A/d)^{B} \tag{36}$$

MAX%	K	A	B
95%	-0.350	0.131	0.15

Using the results of the SWPCD study and this study, Table 10-2 displays the anticipated maximum efficiency ratios and minimum EMCs for bioswales. Again, since the data is rather sparse, reference is made to the filter strip data to project minimum EMCs for certain pollutants. As a result the values are nearly identical to that projected for filter strips, which is to be expected, since similar removal processes by exposure to vegetation are involved.

Table 10-2: Maximum Efficiency ratios and Minimum EMCs

POLLUTANT	TSS	PP	SP	ON	NH4	NO3	CU	ZN
MAXIMUM REDUCTION	95%	95%	45%	90%	70%	45%	85%	85%
MINIMUM EMC (mg/l)	4	0.010	0.005	0.40	0.15	0.15	0.002	0.006

Note that relatively poor reduction (50% compared to 75%) was noted at flow depths of 10 cm (0.33 feet), while good results occur at depths up to 7.5 cm (0.25 feet). For these reasons, biofiltration swales should be designed so that the maximum flow depth does not exceed 0.25 feet during the design flow event, unless a dense uncut stand of native grasses is provided. If swales operate at even lower depths, the performance will be even better.

Since bioswale flow depths need to be totally submerged for decent results, their filtering mechanisms would seem to correspond to that of filter strips. In this light, it is instructive to calculate the retention time in a filter strip, using the sheet flow equation (6), and allocating hydraulic loading as excess precipitation, as is used for impervious disconnection. At a hydraulic loading rate of 12 cu.ft./ft. into a 30 foot filter strip, the resulting excess precipitation would be 0.4 feet. Added to 1.5 inches of rainfall depth, this is a rainfall depth of 7.2 inches. Using equation (6) for a 5% slope at roughness value of 0.45, the travel time through the strip is roughly 4.2 minutes, and 3.1 minutes for a 10% slope. Since these times are at the low end for effective biofiltration, this suggests that either filter strip filtration is more effective for a given time interval (perhaps due to stem density in thatch layer), and/or equation (6), with its parameter values, overstates flow velocities.

10.3 BIOFILTRATION SWALE BMPs

It is essential that the swale soil profile promote vegetative growth, and infiltration, if located above the water table. Therefore, bioswales should be constructed into uncompacted soils where possible. However, construction inevitably involves mass grading, reconfiguration of underlying drainage patterns, and substantial compaction, often deep into native soils. Therefore, prior to topsoil return, the compacted subgrade at the bottom of the swale should be overlaid with a coarse sand mix, which is then subsoiled for several feet, to promote infiltration and biological growth. The facility should then be disked after construction before final grading the topsoil.

The BMP design module of DURMM described in Appendix A provides estimates for biofiltration swale performance as a function of loading rate, pollutant levels, length, width, side slopes, longitudinal slope, and surface cover. Design standards, construction specifications and details of biofiltration swales are set forth the Green Technology Standards, Specifications and Details, Appendix B.

Another important benefit of biofiltration swales is their ability to provide detention storage for events larger than the quality event. By installing stone check dams at regular intervals, a bioswale several feet deep can provide enough storage for reducing the peak flow of even the 100 year event. Check dams constructed with a turf reinforcement matting apron on the downstream side to provide a stable substrate to absorb the energy concentrated in the fall over the dam. Check dams thus absorb the energy of high flows, reducing the potential for resuspension of previously deposited sediments in larger storms. Since the flow from the hydraulic jump on the apron immediately enters the pool created by the next check dam, flow velocities remain quite low throughout, even in extreme events.

Using check dams, many of the benefits of an off-line layout can be provided without the need for flow-splitting devices and the loss of space required for an off-line facility. The BMP design module of DURMM described in Appendix A provides estimates for storage as the check dams fill up. A detail of the typical check dam elevation and profile, including grade drop structures, is displayed in Appendix B.

10.4 INFILTRATING BIOFILTRATION SWALE BMPs

A further important benefit inherent to bioswales is their ability to incorporate an infiltration trench along the center. Since filtration occurs down the sides and along the check dam, by the time runoff flows over the check dam into the stone apron it is already well filtered, so contamination of groundwater by metals is less likely. (However, nitrate loads could still be a problem.) Designing the stone apron as an extension of the infiltration trench, filtered runoff from the upslope section will preferentially fill up the infiltration trench before flowing along the swale. Unfiltered runoff into the next section of the swale has to pass all the way down to the next check dam before it is infiltrated at the next apron.

Infiltration performance is addressed by the infiltration trench routine discussed in Chapter 8. The BMP design module of DURMM described Exhibit A presents the calculations of storage and infiltration as the trench fills up and discharges from storm to storm. Details of the typical bioswale incorporating an infiltration trench are displayed in Appendix B. Design standards, construction specifications and details of the infiltration trench design are set forth the Green Technology Standards, Specifications and Details, Appendix B.

In this manner, a bioswale incorporating a series of cascading dams and infiltration trenches can accomplish remarkable results in terms of filtration, infiltration, streambank protection, and peak flow controls, all in one BMP. As a linear feature roughly 18 feet wide, the multipurpose bioswale is not that much wider than the landscaped islands already required for parking lots. Landscaped with trees along the side slopes, bioswales can be easily integrated into the overall site design without excessive loss of usable ground. It is important though, that enough light remains to permit a dense grass cover. At maturity, the trees will provide enough shade to reduce elevated temperatures in swale runoff. Combined with the savings of land as well as expense from not having to construct a structural BMP, this integrated approach is actually more cost effective, not to mention far healthier to the environment.

CHAPTER 11 BIORETENTION BMPs

11.1 BIORETENTION BMP BACKGROUND

The preceding vegetative filtering BMPs are the first line of defense in the nonstructural BMP approach. If thoughtfully incorporated into the site design, biofiltration BMPs can reduce pollutants to acceptable levels by themselves. However, in more intense urban development, where space may be at a premium and/or the runoff EMCs are elevated, additional nonstructural BMPs are necessary.

Bioretention BMPs are a very effective recent development in BMP design. These "living filters" comprise an organic sandy loam at least two feet deep, covered with a layer of mulch and vegetation. Generally located off-line in small depressions designed to intercept the quality storm volume, filtering occurs as runoff percolates through the mulch and soil matrix into an underdrain. Where infiltration rates are high, exfiltration from the facility can replace the need for underdrains. Bioretention BMPs are particularly effective for removing metals and TSS, and phosphorus to a lesser extent. Nitrogen reduction is more variable and less effective (Coffman and Winogradoff, 1998).

Since much of the captured runoff is released by evapotranspiration, bioretention facilities provide mass reductions even greater than that removed by their reduction in EMCs. Underdrain effluent from bioretention facilities can be up to 12° C cooler than the temperature of incoming runoff (Davis and others, 2000b), providing excellent thermal protection to the receiving waters. These aspects of bioretention facilities make them particularly attractive as a nonstructural BMP, particularly for intensively used paved areas.

Depending upon the infiltration rates of the soil matrix, bioretention facilities are typically sized to handle a hydraulic loading rate of 1.5 inches per hour. Since hydraulic loading rates control facility sizing, it is important that the facility be located to capture the most polluted runoff from impervious areas, with as few contributions from pervious areas as is possible. Depending upon the *CN* of the contributing watershed, these factors suggest that bioretention facilities be sized at roughly 5% of the drainage area.

If the landscaping is not flood tolerant, surface ponding should be restricted to less than a foot at most, and surface drainage should occur within hours after the rainfall ends (Coffman and Winogradoff, 1998). This is necessary to ensure that such landscaping will bear the occasional immersion. Therefore, bioretention BMPs should be located off-line so extended detention surcharge from larger storms is not a potential problem. However, if facultative wetland species are used, a greater range of flooding regimes is acceptable. Not only can such plants tolerate greater depths for longer times, they can also function in hydrologic conditions that approach constant saturation. For these reasons, DURMM recommends facultative plants for bioretention facilities. As discussed below, denitrifying bioretention facilities require facultative landscaping.

Filtration and adsorption are the two mechanisms of pollutant reduction in bioretention. Adsorption is particularly effective in removing the soluble metals that are not susceptible to filtration. As such, the proper composition of the soil matrix of the facility is very important. Sometimes, additional fines such as sand are needed to ensure adequate percolation rates, but sand has a very low CEC, so soil adsorption potential is low. If there is too much sand, efficiency is reduced (Davis and others 2000b), because either adsorption is too low or infiltration rates are too high. Therefore, the proportion of sand should be only what is needed to provide adequate infiltration, with the balance in an organic soil/compost mix.

11.2 BIORETENTION BMP RESULTS

If the infiltration rates are adequate, laboratory experiments suggest that topsoil is an excellent medium, as organic soils have 15 times the CEC of mineral soils on a weight basis (Brady, 1990). Column tests indicate that dissolved copper, zinc, and lead all have similar adsorption rates within a topsoil matrix. The mulch layer is also particularly important, providing adsorption coefficients three times that of the soil matrix (Davies and others, 2000a). To ensure adequate infiltration rates, the organic soils should be augmented with fines so the final mix is less than 15% clay. For best results, the pH should be close to neutral so zinc adsorption is maximized.

Recently, Davis and others (2000a, 2000b) published two studies of bioretention performance. The first report was a laboratory study of two pilot bioretention boxes comprising a sandy loam topsoil with 0.6% organic matter and a CEC of 29 meq/kg, relatively low values for optimal adsorption. A surface layer of shredded hardwood mulch was interspersed with several junipers to replicate field conditions as accurately as possible. Depths of the two boxes were 2.5 and 3.5 feet, with sample ports at intermediate depths to extract effluent as it passes through the soil matrix (Davis and others, 2000a).

A synthetic urban runoff "cocktail" was used to ensure uniform input concentrations. Applied at 4.1 cm/hr for 6 hours, this application rate was designed to represent runoff from a rainfall event of 1.5 cm over a drainage area with a runoff coefficient of 0.8 and 20 times the surface area of the facility. While this application volume is only 30% of the quality storm depth of 5.0 cm recommended in Chapter 4, it is applied over 6 hours instead of the 24-hour distribution of the quality event. If the first 10 hours of the latter event are essentially dry, this represents an average rainfall rate of 0.36 cm/hr over 14 hours, similar to the 0.25 cm/hr rate used in the experiment.

Nonetheless, surface ponding up to 7 inches deep was observed once the facilities had become saturated. While the shallower box percolated at 1 to 2 cm/hr, infiltration rates in the deeper box were as low as 0.3 to 0.4 cm/hr, and ponding remained for roughly two days after application. However, drainage from the boxes was restricted to the small diameter observation port, instead of being allowed to freely drain downward into an underlying soil or underdrain, as would be the case in the field, so these slow rates may be an artifact of the experimental design. As both boxes were comprised of identical soils, this also highlights the inherent variability of soils, suggesting that the proper composition of, and low compaction, of a thoroughly mixed soil matrix is essential.

Results from the effluent sampling in the pilot study are displayed in Table 11-1. Output concentrations are calculated as the average reduction percentage times input concentration. Except in the case of phosphorus, ammonia, and nitrate, reductions were high in all sampling ports. Applied as soluble P, the phosphorus reductions were not nearly as high in the upper ports as that seen in the output effluent. Phosphorus reductions were primarily due to adsorption. This is the primary relationship involved in determining the required depth of the facility, as depths of less than 2 feet provided substantially less reduction in phosphorus levels.

In this analysis, organic N is allocated as the residual of TKN less ammonia. Organic N reductions varied from 84% to –64%, suggesting minimal reductions on average. Whether dissolved or particulate, the widely varying reductions of organic N concentrations do not seem to follow the trends discussed in Chapter 3, where concentrations of organic N are relatively low in base flow, even where they are high in surface runoff. As a substantial component of urban runoff, organic N responses to bioretention are a need for future research. Nitrate reduction was actually negative in the upper ports, with minor efficiency ratios overall. Negligible reductions in ammonia levels were also observed in the upper ports, but since ammonia is adsorbed onto soils, reductions had increased substantially by the bottom. These results suggest that organic N and ammonia captured in the upper layers are transformed into nitrate between tests (Davies and others, 2000a), a conclusion others have reached for the filtration results discussed above.

Analysis of the filter matrix indicated that the mulch retained very high concentrations of metals compared to the soils. However, since mulch is a much smaller proportion than soils by weight, it retained only 20% of the applied metals, with the balance remaining in the soils. This suggests that regular replacement of the mulch layer would improve performance and useful life. Accumulation rates in the soils indicated a useful life of nearly 60 years before the soils matrix becomes saturated, or longer if the mulch is replaced regularly.

Table 11-1: Input and Output EMCs and Efficiency Ratios in Pilot Bioretention Tests

PARAMETER	NO3	NH4	TKN	ON	SP	Zn	Pb	Cu
AVERAGE INPUT CONCENTRATION (mg/l)								
SMALL		1.20	3.50	2.30	0.44	0.600	0.061	0.140
LARGE	0.34	2.40	2.80	0.40	0.52	0.590	0.054	0.064
AVERAGE OUTPUT CONCENTRATION (mg/l)								
SMALL		0.48	0.88	0.40	0.13	<0.025	<0.002	<0.002
LARGE	0.26	0.50	0.90	0.39	0.10	<0.025	<0.002	0.005
EMC REDUCTION								
SMALL		60%	75%	83%	71%	>97%	>98%	98%
LARGE	24%	79%	68%	2%	81%	>98%	>98%	92%

Following the pilot study, the same research team studied field performance of two bioretention facilities in Maryland. The Greenbelt facility constructed in 1992 incorporated well-established grass and shrubs on a mostly soil matrix. The Landover facility constructed in 1998 had less landscaping on a filter media of 50% sand, 20-30% topsoil, and 20-30% leaf mulch. Both facilities were tested with the same synthetic runoff at the same application rate as the pilot tests. Antecedent moisture conditions were favorable for infiltration (Davies and others, 2000b). Results are displayed in table 11-2.

Note that the Greenbelt facility performed as well as the pilot studies, all of which used soils as the media. However, the Landover facility had poorer performance in terms of metals reduction. The authors note that even though the Landover facility had a good mulch layer, which should have effectively removed metals, observed reductions were less than optimal. The possibility of preferential flow through the porous media was discounted since nutrient reductions were similar in each test. However, they also noted that the Greenbelt facility had a higher soil to fines ratio, increasing the potential for adsorption. Since all of the better performing facilities had a topsoil media, this suggests that the mixture used in the Landover facility could be improved. This is an important issue for future research.

Table 11-2: Input and Output EMCs and Efficiency Ratios in Field Bioretention Tests

PARAMETER	NO3	NH4	TKN	ON	SP	Zn	Pb	Cu
INPUT CONCENTRATION (mg/l)								
GREENBELT	0.33	2.60	3.5	0.90	0.52	0.53	0.042	0.066
LANDOVER	1.30		6.9		0.83	1.10	0.054	0.120
OUTPUT CONCENTRATION (mg/l)								
GREENBELT	0.28	0.22	1.65	1.47	0.19	<0.025	<0.002	<0.002
LANDOVER	1.10		2.3		0.11	0.39	0.016	0.069
EMC REDUCTION								
GREENBELT	16%	92%	52%	-64%	65%	>95%	>95%	97%
LANDOVER	15%		67%		87%	64%	70%	43%

Hsieh and Davis (2202) recently reported results for a subsequent study of bioretention in columns. In this study, columns were filled with a variety of different media and the resulting reduction efficiencies measured. Removal of oil and grease was excellent (greater than 99 percent) as was the removal of lead, which was adsorbed onto TSS, that was also removed at high rates. Nitrate removal was quite low (1 percent to 43 percent). Sand performed very poorly for nitrate, while mulch performed the best.

Phosphorus removal was variable, ranging from 5 percent to over 80 percent. It was noted that mulch dominated columns had poor removal rates and slow infiltration rates, while sand had 80 percent removal and high infiltration rates. For this reason, mulch is not considered a good medium for phosphorus removal. Since it also decomposes rapidly, mulch is not recommended as part of the bioretention media, unless nitrate removal is identified as a problem, and mulch can be reliably added on a regular basis to replace that lost by decomposition.

This relationship results in a counterintuitive trend where the better the infiltration rate was, the better the removal rates were. Even though sand removed phosphorus at high rates in this study, it seems unlikely that it would continue to perform at such high rates once its CEC sites become saturated. Dissolved orthophosphate would then pass through unimpeded. For this reason, proportions of sand over 90 percent are not recommended.

11.3 BIORETENTION BMP KINETICS

The preceding discussion demonstrates the excellent potential of bioretention facilities for removing metals, soluble P, and ammonia from urban runoff. Combining the better results from Tables 11-1 and 11-2, Table 11-3 sets forth the irreducible concentrations and maximum reduction percentage possible from bioretention facilities. Since DURMM does not account for N transformations, the maximum nitrate efficiency ratio is 20%, and organic N reductions are estimated at 25%. Although there were no measurements of TSS and particulate P reductions, the metals reduction percentage suggest similar reductions for TSS. Since some of the particulate P will undergo transformations to soluble forms, its net reductions would be less than TSS but more than soluble P. It is thus estimated at 85% in this analysis.

At a given depth, there does not seem to be any design factors that provide incremental changes in efficiency ratios. Instead, two thresholds should be met in all designs: a minimum soil media depth of 2.5 feet (76 cm) for optimal phosphorus reduction; and a maximum loading rate of 1.5 inches/hour over a 12 hour period for a one inch event. Additional research may provide data to ascertain if flushing effects occur at higher rates. Even though one pilot facility had ponding problems with a 6-hour period, this is likely to be due to drainage from the facility being restricted to the small diameter observation port. Since there were no problems with ponding on the field studies, the design loading rate and 12 hour application period seems reasonable. As discussed above, the proper composition of the filter media is essential.

As Table 11-3 indicates, bioretention facilities can provide excellent reductions in metals, phosphorus and TSS. However, since nitrate can comprise much of the total N in urban runoff, the typical aerobic bioretention facility could still release unacceptably high levels of nitrate where the receiving waters are nitrate limited.

Table 11-3: Maximum Efficiency Ratios and Minimum EMCs for Bioretention Facilities

POLLUTANT	TSS	PP	SP	ON	NH4	NO3	CU	ZN
MAXIMUM REDUCTION	97%	95%	85%	85%	90%	24%	99%	99%
MINIMUM EMC (mg/l)	3	0.02	0.10	0.35	0.20	0.25	0.002	0.002

The BMP design module of DURMM described in Appendix A provides estimates on bioretention facility performance as a function of loading rate, pollutant levels, length, width, and side area. Infiltration performance is addressed by the infiltration trench routine discussed in Chapter 8. The BMP design module of DURMM described Exhibit A presents the calculations of storage and infiltration as the facility fills up and discharges from storm to storm. Details of the typical infiltration trench are displayed in Appendix B. Design standards, construction specifications and details of the bioretention facility design are set forth the Green Technology Standards, Specifications and Details, Appendix B.

11.4 DENITRIFYING BIORETENTION

To address the issue of nitrate loads, members of Davis team reported results from column tests designed to provide nitrate removal by denitrification (Kim and others, 2000). Experiments were designed to screen out the best carbon/electron source from among the candidates alfalfa, newspaper, leaf mulch, sawdust, wood chips, and wheat straw. An inorganic electron donor, sulfur was also evaluated in terms of two different particle sizes, 0.6 to 1.18 mm and 2 to 2.36 mm. Limestone was added to buffer the acid production from sulfur oxidation. 40 cm high by 6.4 cm diameter columns with these media were inoculated with secondary effluent from an activated sludge plant for 2 days. Anoxic synthetic runoff was then introduced at 4 cm/hr. Removals were then measured after 35 to 40 days of retention.

Over this period, newspaper and wood chips were the best organic electron sources, providing nearly complete denitrification without other adverse effects. Leaf mulch was less effective at 60% reduction, while alfalfa released odors, turbidity, and 2-3 mg/l TKN. Wheat straw also had high levels of turbidity and TKN, while wood chips and sawdust had low turbidity. However, sawdust had lower reductions in nitrate levels than the wood chips and newspaper, which approached 100% reduction in nitrate levels.

Of the sulfur experiments, the smallest particle size performed best, with nitrate reductions close to 92%, while the larger particles reduction was 33%. The better results with the smaller particle sizes were attributed to their more than doubled surface to volume ratio. However, there is some concern that some of the nitrate is leaving the system as nitrite. Longer retention times were thought to lower the nitrite levels.

The TKN release from alfalfa and wheat straw was attributed to the relatively low C:N ratio in these materials, which tends to promote conversion of organic N to ammonia (ammonification or mineralization). The authors also noted that sulfate-reducing bacteria could reduce nitrate to ammonia under anaerobic conditions when there is a high carbon to nitrate ratio, which would conserve total N. It was thought that this effect would decline over time.

The hydraulic loading rate and time span of the experiment need to be evaluated in terms of their applicability to urban runoff events. The ratio of event volume to interevent interval controls average runoff loading rates during field conditions. However, the 35 to 40 day time span of the experiment exceeds typical intervals between runoff events by a factor of 10. No data is presented for reductions in nitrate levels at the shorter intervals of interest in BMP design (typically 2-4 days between events). Rate kinetics may be inferred from the sulfur experiments where the extent of denitrification seems proportional to surface area. The decline in reduction with larger size particles suggests that they should be more effective if given a longer retention time; conversely, the smallest particles would be less effective at a shorter time frame. If this were the case, sulfur at any size would seem to be ineffective at the shorter time periods of interest.

Assuming 40% in pore space, 16 cm of runoff would fill the columns in roughly 4 hours. Containing some 500 cc of runoff at a nitrate concentration of 2.0 mg/l, the total load of nitrate N would be 1.0 mg. Normalized by the column area of 0.0032 m^2, this represents a load of 3.1

kg/ha. Given a 16:1 ratio of runoff to rainfall similar to that used in the previous pilot and field experiments, this implies a total rainfall volume of 1 cm, well below the 5.0 cm recommended in Chapter 4. At an annual precipitation capture of 35 cm, total annual denitrification would be roughly 35 times 3.1 kg/ha, or 109 kg/ha/yr.

The likely effects of higher loading rates, N transformations, and shorter retention time can be clarified by analysis of the literature on N processes in the landscape. The required annual denitrification of 109 kg/ha/yr is similar to the average annual denitrification rates in forest soils amended with nitrate (Groffman and Tiedje, 1989). Ammonia in streamflow from agricultural areas is less than 2% of total N (Correll and others, 1994), thus the sulfate reduction pathway does not seem to occur in the field. In agricultural fields where roughly 2% of the organic N pool is mineralized per year, high C:N ratios in cover residues substantially reduce nitrate losses (Baker and Senft, 1992). These and other field studies confirm that high C:N ratios determine the potential for denitrification (Drury and others, 1991, and many others). A similar relationship is likely to exist for the column experiments.

As to the retention time necessary for complete denitrification, denitrification rates in pasture soil cores under conditions optimal for denitrification have been measured as high as 5 kg/ha/day (Colburn, 1993). Normalized over column area, this rate corresponds to 67 μg/hr. However, nitrate concentrations in the soil cores were as high as 24 mg/l, 12 times the 2 mg/l used in the columns. Colburn (1993) proposed the following equation for estimating denitrification rate D as a function of nitrate concentration N, temperature T and soil moisture content W:

$$D = Ne^{(0.1W+0.1T-8.3)} \qquad (37)$$

Assuming that the values of T and W in the soil cores represent field conditions typical for bioretention facilities, denitrification rates are then directly proportional to nitrate concentrations. This implies that the rates in the columns would be 1/12 of that observed in the field cores, or around 6 μg/hr. Over a 72 hour interevent interval, the amount of nitrate N reduced at this rate would be 0.43 mg, or 43% of the applied N.

Given that nitrate concentrations in urban runoff are typically lower than 2 mg/l, the removal rate in soils under field conditions would be even lower. However, nitrate reduction in soils is localized to microsites within the soil profile (Parkin, 1987), whose activities dominate the denitrification response of soil cores (Christensen and others, 1990). Since the column media is optimized for nitrate reduction throughout, its removal rate per unit area should be considerably higher than soils. Therefore, the potential for reducing nitrate in bioretention facilities using a sawdust media appears to be quite promising, although complete denitrification may not occur between closely spaced large events. As indicated in the pilot and field studies, there does appear to be some nitrate reduction occurring in the topsoil bioretention media.

Kim and others (2000) propose a denitrifying cell below a 2' bioretention layer, with denitrified effluent discharged from the bottom as it is surcharged from above. However, given a permanently saturated zone at the bottom surface of the bioretention media, capillary suction would induce moisture into the bioretention layer above. This would induce anaerobic conditions to persist for several days after a storm event, or even weeks during winter. Under such circumstances, nitrification of ammonia would be inhibited, reducing potential reduction in total N by the denitrification layer.

To avoid capillary suction, a capillary fringe barrier in the form of several inches of coarse sand would be required between the bioretention and denitrification layers. The required volume of the denitrifying layer should be equal to the design event runoff volume, less soil storage capacity in the bioretention layer. This permits time for denitrification of this volume to occur during the average interevent interval of around three days. Given an average of 20% of the media volume in macropores, a bioretention layer 60 cm deep would provide for 12 cm of storage. At a 40% void ratio, 40 cm of runoff (assuming the same ratio of impervious area to biofiltration area as used above; equal to 16 times the 2.5 cm design event), less 12 cm, would require a denitrification layer 70 cm deep. Design depths would be adjusted in relation to the volume of runoff divided by surface area.

The preceding discussion on denitrification in agricultural soils raises an interesting possibility for the design of bioretention facilities. Since soils denitrify at high rates when saturated, the bioretention layer could incorporate fine sulfur and sawdust as the fines fraction with a topsoil adsorption fraction, overlaid upon a denitrifying layer of saturated sawdust. During saturated conditions, the bioretention soil layer would also denitrify nitrate from incoming runoff and that which has been nitrified from organic N. This would improve interevent efficiency ratios, and perhaps reduce the required volume of the denitrifying layer. Facultative plant species would be required since the root zone would cycle between aerobic and anaerobic conditions, which would stress exclusively upland plant species.

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25 October 2004

UNIFIED FACILITIES CRITERIA (UFC)

DESIGN: LOW IMPACT DEVELOPMENT MANUAL

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UNIFIED FACILITIES CRITERIA (UFC)

DESIGN: LOW IMPACT DEVELOPMENT MANUAL

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing ACTIVITY)

AIR FORCE CIVIL ENGINEERING SUPPORT AGENCY

RECORD OF CHANGES (changes are indicated by \1\.../1/)

Change No.	Date	Location

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCESA) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request (CCR). The form is also accessible from the Internet sites listed below.

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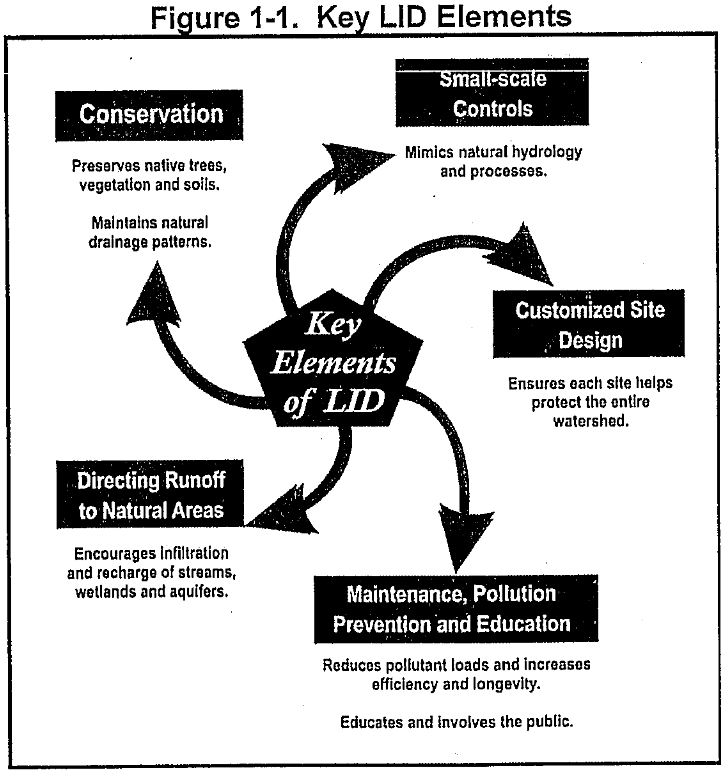
CHAPTER 1

INTRODUCTION TO LID AND MANUAL OVERVIEW

1-1 **DEFINITION OF LID.** Low Impact Development (LID) is a stormwater management strategy concerned with maintaining or restoring the natural hydrologic functions of a site to achieve natural resource protection objectives and fulfill environmental regulatory requirements. LID employs a variety of natural and built features that reduce the rate of runoff, filter out its pollutants, and facilitate the infiltration of water into the ground. By reducing water pollution and increasing groundwater recharge, LID helps to improve the quality of receiving surface waters and stabilize the flow rates of nearby streams.

LID incorporates a set of overall site design strategies as well as highly localized, small-scale, decentralized source control techniques known as Integrated Management Practices (IMPs). IMPs may be integrated into buildings, infrastructure, or landscape design. Rather than collecting runoff in piped or channelized networks and controlling the flow downstream in a large stormwater management facility, LID takes a decentralized approach that disperses flows and manages runoff closer to where it originates. Because LID embraces a variety of useful techniques for controlling runoff, designs can be customized according to local regulatory and resource protection requirements, as well as site constraints. New projects, redevelopment projects, and capital improvement projects can all be viewed as candidates for implementation of LID.

Figure 1-1. Key LID Elements



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1-2 **BACKGROUND ON THE USE OF LID.** The use of LID was pioneered in the 1990s by the Prince George's County, Maryland Department of Environmental Resources (PGDER). Prince George's County has a population of over 800,000, and land uses within the County are very diverse, ranging from sparsely populated natural and agricultural areas to densely populated urban centers. The LID effort in Prince George's County began with the development and use of bioretention cells. A bioretention cell is created by replacing existing soil with a highly porous soil mixture, grading the area to form a shallow depression, and replanting the area with specially selected vegetation. The vegetation must be able to tolerate temporarily saturated soil conditions as well as the pollutants contained in the local runoff. When it rains, bioretention areas collect the runoff and then filter out the pollutants as the water passes down through the soil.

The County's initial experience with bioretention led to a full-scale effort to incorporate LID into the County's resource protection program. In 1998, the County produced the first municipal LID manual. This was later expanded into a nationally distributed LID manual published in 2000.[1] A feasibility study was prepared by the Low Impact Development Center in 2002 that provided guidance on how LID could be used to retrofit urban areas.[2] Numerous municipalities, including Portland, Oregon,[3] are incorporating LID techniques into their urban resource protection programs. Although LID concepts and techniques are new to many planners in the United States, many of these techniques have been successfully used in Europe and Asia for many years.[4]

Several successful pilot projects have been constructed by the Navy and other Department of Defense (DoD) agencies during the last several years. The effectiveness of these projects in managing runoff, reducing construction and maintenance costs, and creating ancillary benefits such as community involvement has created significant interest in LID. The challenge is to adapt these approaches and techniques to the unique requirements of DoD facilities on a wider scale.

1-3 **INTRODUCTION TO UFC.** This UFC provides guidelines for integrating LID planning and design into a facility's regulatory and resource protection programs. It will be useful to engineers, planners, maintenance personnel, regulatory compliance staff, and community outreach staff who want a basic understanding of the technical and administrative concepts associated with the design, construction, and maintenance of LID features. The UFC answers the following questions:

- What is LID and what value does it have for DoD facilities?
- What are the basic planning, design, construction, and maintenance considerations?
- How can this approach be incorporated into facility operations?

[1] PGDER, 2000a.
[2] LID Center, 2002.
[3] BES, 2000.
[4] Ibid.

- Where are successful examples of LID DoD facilities and programs?
- What does a typical LID design look like?
- Where can additional guidance be obtained?

This UFC is divided into ten chapters, including this introductory chapter. Chapter 2 provides a brief summary of issues related to compliance and the review process for any DoD project. Chapter 3 discusses regulations that apply to water resource and sustainability concerns for DoD projects, and how implementation of LID will affect compliance. Chapter 4 compares the ways that LID and conventional stormwater management approaches utilize hydrologic data and concepts in the design process. Chapter 5 discusses the goals of an LID design and the principles and strategies to meet them. Chapter 6 provides an overview of LID devices and the objectives they are designed to meet. Chapter 7 discusses the relative benefits of LID and conventional stormwater management practices. Chapter 8 details the appropriate use, cost, and maintenance issues for the LID devices introduced in Chapter 6. Chapter 9 provides a detailed outline of the LID planning process. Finally, Chapter 10 offers two examples of LID techniques put into practice, with accompanying calculations.

1-4 **LID SITE DESIGN STRATEGIES.** The goal of LID site design is to reduce the hydrologic impact of development and to incorporate techniques that maintain or restore the site's hydrologic and hydraulic functions. The optimal LID site design minimizes runoff volume and preserves existing flow paths. This minimizes infrastructural requirements. By contrast, in conventional site design, runoff volume and energy may increase, which results in concentrated flows that require larger and more extensive stormwater infrastructure.

Generally, site design strategies for any project will address the arrangement of buildings, roads, parking areas, and other features, and the conveyance of runoff across the site. LID site design strategies achieve all of the basic objectives of site design while also minimizing the generation of runoff. Some examples of LID site design strategies discussed in this UFC include:

- Grade to encourage sheet flow and lengthen flow paths.
- Maintain natural drainage divides to keep flow paths dispersed.
- Disconnect impervious areas such as pavement and roofs from the storm drain network, allowing runoff to be conveyed over pervious areas instead.
- Preserve the naturally vegetated areas and soil types that slow runoff, filter out pollutants, and facilitate infiltration.
- Direct runoff into or across vegetated areas to help filter runoff and encourage recharge.

- Provide small-scale distributed features and devices that help meet regulatory and resource objectives.

- Treat pollutant loads where they are generated, or prevent their generation.

1-4.1 **LID Devices.** Reevaluate the site design once all of the appropriate site design strategies are considered and proposed to determine whether the stormwater management objectives have been met. Stormwater management controls, if required, should be located as close as possible to the sources of potential impacts. The management of water quality from pavement runoff, for example, should utilize devices that are installed at the edge of the pavement. These types of controls are generally small-scale (because the site planning strategies have created small-scale drainage areas and runoff volumes) and can be designed to address very specific management issues. The objective is to consider the potential of every part of the landscape, building(s), and infrastructure to contribute to the site stormwater management goals. When selecting LID devices, preference should be given to those that use natural systems, processes, and materials. The following list briefly defines the LID devices (or IMPs) described in this UFC.

1-5 **BASIC LIST OF IMPs.** Here is a basic list of IMPs that are available. More detailed descriptions are presented in Chapter 8. Appendix B contains a list of acronyms and abbreviations cited in the UFC.

Bioretention: Vegetated depressions that collect runoff and facilitate its infiltration into the ground.

Dry Wells: Gravel- or stone-filled pits that are located to catch water from roof downspouts or paved areas.

Filter Strips: Bands of dense vegetation planted immediately downstream of a runoff source designed to filter runoff before entering a receiving structure or water body.

Grassed Swales: Shallow channels lined with grass and used to convey and store runoff.

Infiltration Trenches: Trenches filled with porous media such as bioretention material, sand, or aggregate that collect runoff and exfiltrate it into the ground.

Inlet Pollution Removal Devices: Small stormwater treatment systems that are installed below grade at the edge of paved areas and trap or filter pollutants in runoff before it enters the storm drain.

Permeable Pavement: Asphalt or concrete rendered porous by the aggregate structure.

Permeable Pavers: Manufactured paving stones containing spaces where water can penetrate into the porous media placed underneath.

Rain Barrels and Cisterns: Containers of various sizes that store the runoff delivered through building downspouts. Rain barrels are generally smaller structures, located above ground. Cisterns are larger, are often buried underground, and may be connected to the building's plumbing or irrigation system.

Soil amendments: Minerals and organic material added to soil to increase its capacity for absorbing moisture and sustaining vegetation.

Tree Box Filters: Curbside containers placed below grade, covered with a grate, filled with filter media and planted with a tree in the center.

Vegetated Buffers: Natural or man-made vegetated areas adjacent to a water body, providing erosion control, filtering capability, and habitat.

Vegetated Roofs: Impermeable roof membranes overlaid with a lightweight planting mix with a high infiltration rate and vegetated with plants tolerant of heat, drought, and periodic inundation.

CHAPTER 2

INSTITUTIONAL ISSUES

2-1 **INTRODUCTION.** As with other types of construction projects, LID designs must meet DoD criteria and specifications before they can be approved. In addition, state and local zoning requirements and building codes may apply. This section provides an overview of these institutional issues and how they can be addressed effectively.

2-2 **COMPLIANCE WITH DOD CRITERIA.** Three primary concerns associated with obtaining DoD approval for using LID are listed below.

2-2.1 **Compliance with DoD Design Criteria.** LID techniques will comply with DoD design criteria. This UFC has the approval of Naval Facilities Engineering Command for compliance with Navy and DoD criteria and is written with the express purpose of assisting site engineers with satisfying DoD design criteria.

2-2.2 **Cost-Effectiveness.** The cost-effectiveness of LID-based projects may affect DoD approval. LID projects that incorporate newer technology may involve higher design and construction costs and may take more time to receive approval as a result. Whether or not this is the case for a particular site will depend on the level of experience that the project managers, engineers, and contractors have with LID techniques, and on the receptiveness of permitting authorities to LID practices. As with any new approach, the cost of implementing LID will decrease as institutional experience increases and the benefits of using LID are realized in practice.

2-2.3 **Antiterrorism/Force Protection.** All DoD facilities must comply with UFC 4-010-01, *Design: DoD Minimum Antiterrorism Standards for Buildings*. If any conflict occurs between this UFC and UFC 4-010-01, the requirements of UFC 4-010-01 take precedence.

2-3 **FEDERAL, STATE, AND LOCAL GOVERNMENT ACCEPTANCE.** Every new construction or retrofit project must meet applicable federal, state, and local regulatory requirements pertaining to construction materials, elevation and drainage, stormwater management, historic features, and wetlands protection. Because LID may be a new concept in some areas, DoD personnel may have to plan for additional reviews to gain support for LID as an effective alternative to traditional stormwater management control.

2-4 **BUILDING CODES.** For some DoD facilities, all projects, including LID designs, must meet UFC 1-200-01, *Design: General Building Requirements*. As with any project, the project manager or contractor must ensure that the project meets all applicable zoning, land use, or development regulations and must identify any special waivers, modifications, or processes that may be needed to gain approval. The design details should be evaluated for conformance with standard building codes to address access, safety and health issues.

CHAPTER 3

WATER RESOURCE PROBLEMS, ISSUES, AND CHALLENGES

3-1 **INTRODUCTION.** Stormwater management efforts at DoD facilities will have a higher value when the design objectives involve not only the control of runoff at the drainage area outlet but also on-site water conservation, strategic conveyance of runoff, pollution prevention, stormwater treatment, and habitat preservation. DoD facility staff, however, currently face several significant challenges when pursuing these objectives because they must simultaneously consider mission, environmental, facility and budgetary goals. In many instances, LID can benefit several of these goals at the same time. For instance, LID can help to reduce expenditures on piped or channelized conveyance systems and large retention basins, because a fundamental LID technique is to provide storage and treatment on-site before runoff builds up in significant quantities. The following sections present the key issues and challenges associated with implementing LID on DoD facilities.

3-2 **COASTAL ZONE ISSUES.** Coastal zone issues are of particular concern for the DoD. DoD facilities located on the coast or along major water bodies often receive increased public and regulatory scrutiny. The primary stormwater management challenge facing DoD facility managers is minimizing uncontrolled runoff from industrial operations (e.g., ship maintenance operations and fueling areas) and from impervious areas (e.g., cantonment areas, docks, parking lots). Retrofitting a site using strategically placed LID components will enable DoD to conduct operations on a landscape that is less detrimental to water quality.

3-3 **REGULATORY COMPLIANCE.** This section lists the major federal laws concerning stormwater management and natural resource conservation at DoD facilities, and how implementing LID can help reduce the burdens associated with complying with these regulations.

3-3.1 **Clean Water Act.** The Clean Water Act (CWA) is the primary Federal law concerned with protecting the quality of the nation's waters. The major CWA programs pertaining to stormwater management are:

3-3.1.1 **Section 303. Total Maximum Daily Loads.** Section 303 of the CWA requires states, territories, and authorized tribes to develop lists of impaired waters and establish total maximum daily loads (TMDLs) allowable for these waters. States use the TMDL process to allocate pollutant loadings among pollution sources in a watershed and to provide a basis for establishing controls to reduce both point and non-point source pollutant loadings. LID can be used to help states meet TMDL targets in designated watersheds.

3-3.1.2 **Section 311. Spill Prevention, Control and Countermeasure Requirements.** Section 311 addresses pollution from oil and hazardous substance releases, providing EPA and the U.S. Coast Guard with the authority to establish a program for preventing, preparing for, and responding to oil spills that occur in navigable waters of the United States. EPA requires that certain facilities develop and implement oil spill prevention, control, and countermeasures (SPCC) plans. The goal of an SPCC plan is to ensure that facilities install containment and other countermeasures to prevent oil spills from reaching navigable waters.

3-3.1.3 **Section 319. State Non-Point Source Management Program.** This section delegates the regulation of non-point source pollution to the states and establishes the Non-Point Source Management Program. Although Section 319 of the CWA includes no enforcement mechanism to ensure that states actually develop and implement programs, CWA Section 303 requires that states identify all the activities that are causing a water body to be impaired, including non-point source pollutants, and develop mitigation plans.

3-3.1.4 **Section 401. Certification and Wetlands.** Section 401 of the CWA gives states, territories and authorized tribes the authority to review and approve, deny or condition all Federal permits or licenses that might result in a discharge to State or Tribal waters, including wetlands. State wetland water quality standards will limit the degradation of its waters and wetlands resulting from Federal activity. (In states without such standards, Federal water quality standards apply.) In order to obtain state certification, a development project may be required to prevent potential degradation of receiving waters caused by the discharge of stormwater runoff. LID can be used to reduce pollutant concentrations in stormwater runoff. Because of their small footprint and their manner of operation (i.e. filtering and dewatering devices rather than wet systems) LID devices themselves will not be subject to regulation as wetlands.

3-3.1.5 **Section 402. National Pollutant Discharge Elimination System (NPDES) Program.** The CWA prohibits the discharge of any pollutant to waters of the United States from a point source unless the discharge is authorized by a NPDES permit. Facilities that discharge stormwater from certain activities (including industrial activities, construction activities, and municipal stormwater collection systems) require NPDES permits. These facilities must implement commonly-accepted stormwater discharge management controls, often referred to as best management practices (BMPs), to effectively reduce or prevent the discharge of pollutants into receiving waters. Using LID to eliminate the volumes of effluent discharges of permit–requiring activities can help reduce the need for NPDES permits.

For many DoD facilities, the CWA Stormwater Phase II rule will expand their NPDES permitting requirements. Under the CWA Stormwater Phase II rule, EPA (or a state given CWA enforcement authority) can require a facility with a stormwater system to obtain a permit, even if it is not automatically regulated, if the facility's stormwater system discharges via a point source to an impaired water (the CWA 303d list), or to sensitive waters. Facilities that fall under the Phase II rule must develop and implement various BMPs including expanded stormwater management. LID techniques can help a facility to meet stormwater control requirements in a manner that minimizes impacts to the facility and natural environment and reduces the amount of infrastructure to be constructed and maintained.

Stormwater management solutions must qualify as state and local government-approved BMPs and meet technical performance criteria. For example, an infiltration trench must provide a minimum level of pollutant removal as well as meet other performance requirements. A number of regulators are specifically encouraging the use of LID techniques and other innovative stormwater management solutions that reduce pollution associated with runoff. Many already encourage the use of bioretention, dry wells (where permitted), filter strips, vegetated buffers, grassed swales, and infiltration trenches. In some cases, stormwater credits may be given for using LID approaches.

3-3.1.6 **Section 404. Regulation of Dredged or Fill Material.** Section 404 of the CWA establishes programs to regulate the discharge of dredged or fill material into U.S. waters, including wetlands. The U.S. Army Corps of Engineers and the EPA jointly administer Section 404. According to these regulations,[5] no discharge of dredged or fill material can be permitted if a practicable alternative exists that is less damaging to the aquatic environment, or if the nation's waters would be significantly degraded. In other words, a permit applicant must demonstrate that they have:

- taken steps to avoid wetland impacts where practicable;
- minimized potential impacts to wetlands; and
- provided compensation for any remaining, unavoidable impacts through activities to restore or create wetlands.

LID features can reduce potential impacts to wetlands in several ways. First, filtering out pollutants from runoff helps to preserve the quality of water reaching the wetlands. Additionally, enhancing infiltration in the vicinity of the wetlands helps to sustain the supply of groundwater that feeds them. Finally, by reducing runoff energy, LID devices help prevent downstream erosion, reducing the volume of material that must ultimately be dredged from a channel or reservoir.

3-3.2 **Safe Drinking Water Act Wellhead Protection Program.** The Wellhead Protection Program protects the recharge areas of public water system wells from all sources of contamination. Groundwater recharge often results from LID techniques that increase rates of infiltration. Care should be taken, however, to ensure that any pollutants contained in runoff are adequately filtered out before the stormwater percolates down to aquifers in wellhead protection zones.

3-3.3 **Coastal Zone Management Act.** The Coastal Zone Management Act requires DoD facilities located in coastal states with approved coastal zone management programs to conform to the state program. As part of their programs, states must develop and implement coastal non-point source pollution control programs. States may object to permits for activities that are inconsistent with the state's coastal zone management plan. LID techniques can comprise a constructive response to state implementation of a non-point source pollution control program.

[5] http://www.epa.gov/owow/wetlands/facts/fact10.html

3-3.4 **Energy Policy Act of 1992.** The Energy Policy Act of 1992 created conservation and energy-efficiency requirements for the federal government and consumers. The Act requires federal agencies to install, by January 1, 2005, energy and water conservation measures that will achieve acceptable payback periods. (A payback period is the time required to recoup the initial investment in a product or service.) LID techniques such as vegetated roofs and landscape shading can help a facility treat stormwater runoff, meet energy reduction goals, and possibly extend the life of infrastructure such as roofs. Water collected from rain barrels and cisterns for landscaping can be used to reduce a facility's water consumption, again helping to meet the Act's goals.

3-3.5 **Estuaries and Clean Waters Act of 2000.** The Estuaries and Clean Waters Act of 2000 established a program to utilize federal, state and private funding to support locally proposed watershed restoration projects. Under the Act, all Chesapeake Bay agreements are now codified, meaning that all agreements that DoD has signed are now law. Under the Act, federal agencies that own or operate a facility within the Chesapeake Bay watershed must participate in regional and sub-watershed planning and restoration programs. Additionally, the Act states that:

> "The head of each Federal agency that owns or occupies real property in the Chesapeake Bay watershed shall ensure that the property, and actions taken by the agency with respect to the property, complies with the Chesapeake Bay Agreement, the Federal Agencies Chesapeake Bay Unified Plan, and any subsequent agreements and plans."

Lastly, by 2010, the Chesapeake Bay watershed must be off the impaired waters list or it will be subject to TMDL requirements. Stricter discharge limits may result. Wherever discharge limits are imposed, LID techniques can be used to control the discharge of pollutants in stormwater.

3-3.6 **National Environmental Policy Act of 1969.** The National Environmental Policy Act of 1969 requires facilities to conduct and document environmental analyses and seek advice, participation, or comment from appropriate governmental agencies, and inform interested public and private organizations. The analyses include many aspects covering land use, air and water quality, wildlife and their habitats, socioeconomic factors, human health and safety, and natural and historical resources. By incorporating LID into site design, facilities can minimize adverse affects of new development on the environment (e.g., topography, stormwater, vegetation).

3-3.7 **Sikes Act.** The Sikes Act requires facilities to manage natural resources via an approved Integrated Natural Resource Management Plan. This plan serves as the facility plan for managing its ecosystems, including watersheds and wetlands. Consistent with the goals of the Sikes Act, the use of LID techniques will help maintain the natural landscape and its hydrology.

3-4 **DIRECTIVES.** DoD facilities also must meet various Presidential Executive Orders (EOs) or directives in addition to meeting federal laws. This section lists the major directives that relate to stormwater management and conservation and indicates how implementing LID designs can help reduce compliance burdens.

3-4.1 **EO 13148, Greening the Government through Leadership in Environmental Management.** Each agency must strive to promote the sustainable management of federal facility lands through the implementation of cost-effective, environmentally sound landscaping practices and programs designed to reduce adverse impacts on the natural environment. Sustainable environmental management can be implemented directly and visibly through the use of LID.

3-4.2 **LEED Green Building Rating System™.** The U.S. Green Building Council has developed the LEED Green Building Rating System™, a national standard for developing high-performance, sustainable buildings. Projects can earn LEED™ certification for sustainability based on the number of sustainable practices incorporated into the project. DoD facilities that implement LID techniques can receive LEED™ points for limiting the disruption of natural water flows by minimizing stormwater runoff, increasing on-site infiltration, and reducing contaminants. Currently, Navy and Air Force policies encourage the use of the LEED checklist, which the Army soon plans to adopt as well. Other DoD criteria such as the Army's Sustainable Project Rating Tool (SPiRiT), which is adapted from the LEED checklist, may also apply.

3-5 **VOLUNTARY PROGRAMS AND AGREEMENTS.** Partnerships between federal, state, local, and private entities have developed voluntary, watershed-wide guidelines aimed at preserving and restoring water quality in water bodies such as the Potomac River or Chesapeake Bay. One such partnership is the Chesapeake Bay Program, of which DoD is a partner. The Chesapeake Bay Program offers specific guidelines such as providing riparian buffers and implementing new stormwater management technologies in targeted watersheds. (Riparian land is adjacent to a stream or river and has an elevated level of biological activity because of that proximity.[6]) The use of LID as a design approach will help to fulfill the aims of these facilities agreements and partnerships.

3-6 **COSTS.** LID practices offer opportunities to reduce the life cycle cost of a site's stormwater infrastructure. It is impractical to make broad generalizations about costs for stormwater facilities because of the inherent variability between sites and the complexity of management issues. Although initial construction costs for LID practices may be higher than initial costs for conventional stormwater practices, this initial expense is often offset by cost savings in operations and maintenance. This savings is possible because the maintenance of LID features can generally be incorporated into regular landscaping maintenance activities and does not require expensive training or hiring of a separate contractor for maintenance. Details for specific LID practices are presented in Chapter 8.

3-7 **RETROFITS.** Older DoD facilities were developed either with traditional approaches or with no stormwater management at all. Eventually, stormwater management components will have to be installed, replaced or retrofitted – a costly

[6] Lee, 1998.

task. DoD will inevitably need to replace pipes and dredge stormwater ponds. LID techniques, particularly non-structural techniques such as disconnecting impervious areas, can significantly reduce the cost of retrofitting or providing stormwater management.

CHAPTER 4

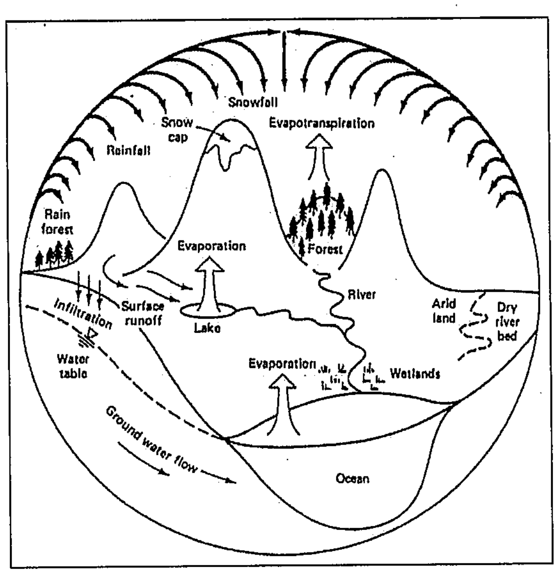
STORMWATER MANAGEMENT USING THE HYDROLOGIC CYCLE APPROACH

4-1 **INTRODUCTION.** Development affects the natural hydrologic cycle as shown in Figures 4-1 and 4-2. The hydrologic cycle consists of the following processes: convection, precipitation, runoff, storage, infiltration, evaporation, transpiration, and subsurface flow.

A hydrologic budget describes the amounts of water flowing into and out of an area along different paths over some discrete unit of time (daily, monthly, annually). Grading, the construction of buildings, and the laying of pavement typically affect the hydrologic budget by decreasing rates of infiltration, evaporation, transpiration and subsurface flow, reducing the availability of natural storage, and increasing runoff. In a natural condition such as a forest, it may take 25 to 50 mm (one to two inches) of rainfall to generate runoff. In the developed condition, even very small amounts of rainfall can generate runoff because of soil compaction and connected impervious areas. The result is a general increase in the volume and velocity of runoff. This, in turn, increases the amount of pollution that is carried into receiving waters and amplifies the generation of sediment and suspended solids resulting from bank erosion.

4-2 **DESIGN INPUTS.** Both LID and conventional stormwater management techniques attempt to control rates of runoff using accepted methods of hydrologic and hydraulic analysis. The particular site characteristics that are considered will depend on the nature of the project. Land use, soil type, slope, vegetative cover, size of drainage area and available storage are typical site characteristics that affect the generation of runoff. The roughness, slope and geometry of stream channels are key characteristics that affect their ability to convey water.

Figure 4-1. Natural Hydrologic Cycle



Source: McCuen, 1998.

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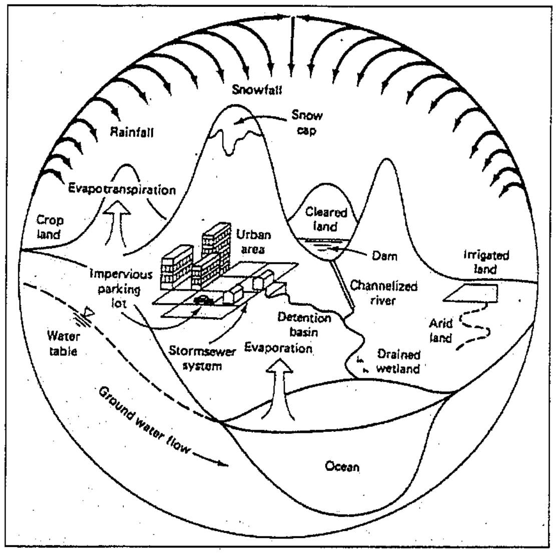
Figure 4-2. Hydrologic Cycle of a Developed Environment



Source: McCuen, 1998.

While conventional approaches to stormwater management design typically include only the hydrologic components of precipitation, runoff conveyance and storage capacity within their scopes, LID design recognizes the significance of other components of the hydrologic cycle as well. How these other components are actually taken into account will depend on the information available and purpose of the design. One LID design objective, for example, may be to maintain a natural groundwater recharge rate for a given site. Determining the appropriate number, size, and location of infiltration devices can require an extensive atmospheric data set (temperature and precipitation) to calculate evapotranspiration rates, along with measures of soil hydraulic conductivity.

The following section describes how LID design can make use of precipitation, storage, infiltration, evaporation, and transpiration data. The discussion includes a brief description of each of these types of data, and compares the use of these data from LID and conventional stormwater management perspectives.

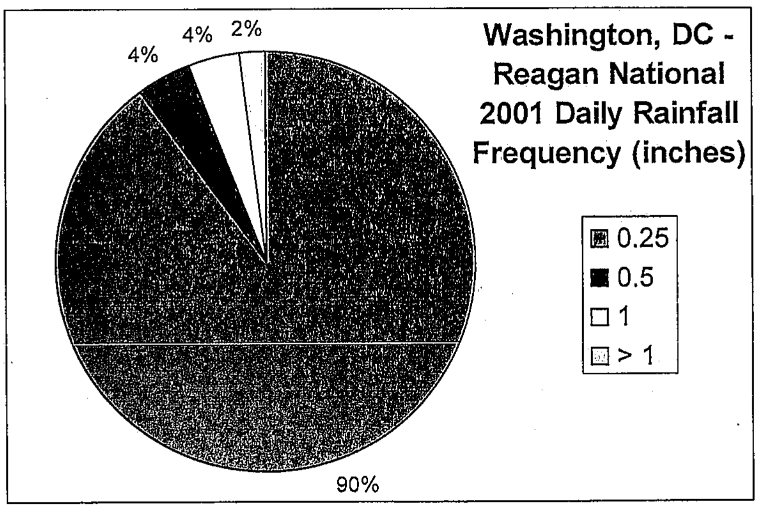
4-3 **PRECIPITATION DATA.** Precipitation data is often analyzed in terms of the frequency at which storm events of different magnitudes and durations occur at a given location. Stormwater management designs may take into account the total annual depths or the volume generated by a storm of a specific frequency and duration (e.g. 2-year 24-hour storm event). Hydrologic models may use precipitation data to develop a synthetic design storm that reflects the pattern and intensity of precipitation for the project location region or use actual gage data from a given storm event.

The level of detail and accuracy of data used is dependent on the requirements of the hydrologic model. For example, to develop a simple water balance for on-site irrigation only a few years of annual rainfall totals may be required. Some advanced urban hydraulic models, on the other hand, may require the collection of rainfall data in 2-minute intervals over several years to determine the appropriate system design.

4-3.1 **LID Precipitation Analysis.** An important approach to analyzing the effectiveness of an LID design is to consider the number of storm events for which the design will provide enough storage and infiltration capacity to capture all of the precipitation on-site. This is useful because maintaining the hydrologic integrity or water balance of a site is better accomplished by managing the frequent smaller events rather than the occasional large events.

For example, in the Washington, D.C. region there are approximately 80 storm events per year that collectively generate approximately 1000 mm (40 in) of precipitation. Approximately 75 of these storm events generate 13 mm (0.5 in) or less of precipitation. Figure 4-3 illustrates this concept.

Figure 4-3. Frequency of Small Storms



Source: NOAA.

This kind of analysis allows the designer to determine the overall storage and infiltration capacity required to control the desired number of storm events within any given year or period. The analysis can also be undertaken in terms of the precipitation depth associated with discrete storm events such as the 1-year 24-hour storm.

4-3.2 **Conventional Precipitation Analysis.** Conventional practices, as well as many state and local regulations, often require site engineers to control only specific events such as the 2-year 24-hour storm events. In the Washington, D.C. area, this would mean reducing the peak runoff to predevelopment rates for only those events in which 76 mm (3 in) of rainfall. Events that occur more or less frequently would be less effectively controlled.

4-4 **STORAGE.** Precipitation may be temporarily detained within site depressions or held in the soil. When the capacity of a depression is exceeded, the water is released as runoff that may be captured further downstream. Water that is not released as runoff will be infiltrated into the soil, taken up by plants, or evaporated back into the atmosphere. Natural land cover often provides depression storage in small undulations in the topography. Greater storage capacity is provided in ponds or lakes.

4-4.1 **LID Storage Concepts.** LID employs site planning and grading techniques to direct or maintain the flow of runoff to naturally occurring storage areas such as wetlands. Keeping the storage area volume stable helps to maintain the existing hydrologic and biological function of the storage area.

An LID design may also include small-scale retention components (retention is defined as the volume of runoff that never reaches the drainage area outlet). Retention can be provided in a variety of ways that not only support the management of runoff, but also supply water for on-site use. For example, a cistern may be used to store and release water for peak flow control as well as to store water for domestic purposes. Additionally, some industrial buildings can provide roof storage and release water for use in cooling systems. Another example, shown in Figure 4-4, is a green wall within a building. The green wall is used to modify temperature and improve air quality by having stored roof water flow across the vegetation.

Capturing runoff in small volumes helps to prevent erosion, because the runoff is less likely to reach damaging flow rates. The distribution of storage components also tends to result in a more robust stormwater management system, because the failure of one component will not cause the entire system to fail. Care must be taken when ponding or storing water to make sure there is adequate flow, infiltration, evaporation, or discharge, and that unwanted carriers of disease such as mosquitoes are adequately controlled.

Figure 4-4. Greenwall

Source: Greenland International Consulting, Inc., Ontario, Canada.

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4-4.2 **Conventional Storage Concepts.** Conventional stormwater strategies often include the storage of water in large centralized end-of-pipe facilities. Site designs direct and convey most runoff as quickly as possible to these facilities and then discharge through an outlet structure at a limited release rate (e.g., 2-year 24-hour pre-development runoff rate). Conventional runoff management techniques can dramatically reduce the flow of runoff into natural storage areas such as wetlands, depriving a variety of organisms of the level of moisture they need.

Conventional approaches can have other negative impacts. By removing opportunities for storage onsite, rates of ground water recharge will be reduced. In addition, the concentrated flow conveyed to large-scale facilities accumulates pollutants and increases the erosive force of the water, which must be slowed down and treated to maintain the natural energy and chemical balance of the ecosystem. An increase in temperature as the water is pooled may also be detrimental to the ecological integrity of the receiving water.

4-5 **INFILTRATION.** Water stored in depressions will infiltrate into the soil at different rates, depending on the soil type and the amount of moisture already in the soil. Some of the water that infiltrates into the ground may then percolate further downward into an aquifer, or travel horizontally and reappear as surface flow in a stream. A portion of the water will be held in the soil and extracted by vegetation.

The capacity of the soil to absorb and infiltrate water is dependent on a variety of factors such as soil structure (e.g., pore spaces and particle size), classification (percentage of sand, silt, and clay) and biological activity (e.g., roots, worms). Water is filtered by the soil system by various mechanisms such as adsorption and chemical and biological reactions. Under natural conditions, a significant portion of the annual precipitation may infiltrate into the ground. As land is developed, however, many natural depressions that would otherwise collect water are eliminated, the soil is compacted, and impervious area is added in the form of buildings and pavement. Consequently, levels of infiltration typically decrease when a site is developed. The additional runoff generated often results in degradation of the watercourse because of bank erosion, increased flooding, and alteration of habitat characteristics.[7]

The infiltration flow patterns and processes are extremely important to maintain the water balance in wetlands and the base flow in stream channels. Figure 4-5 illustrates how groundwater feeds an aquatic system.

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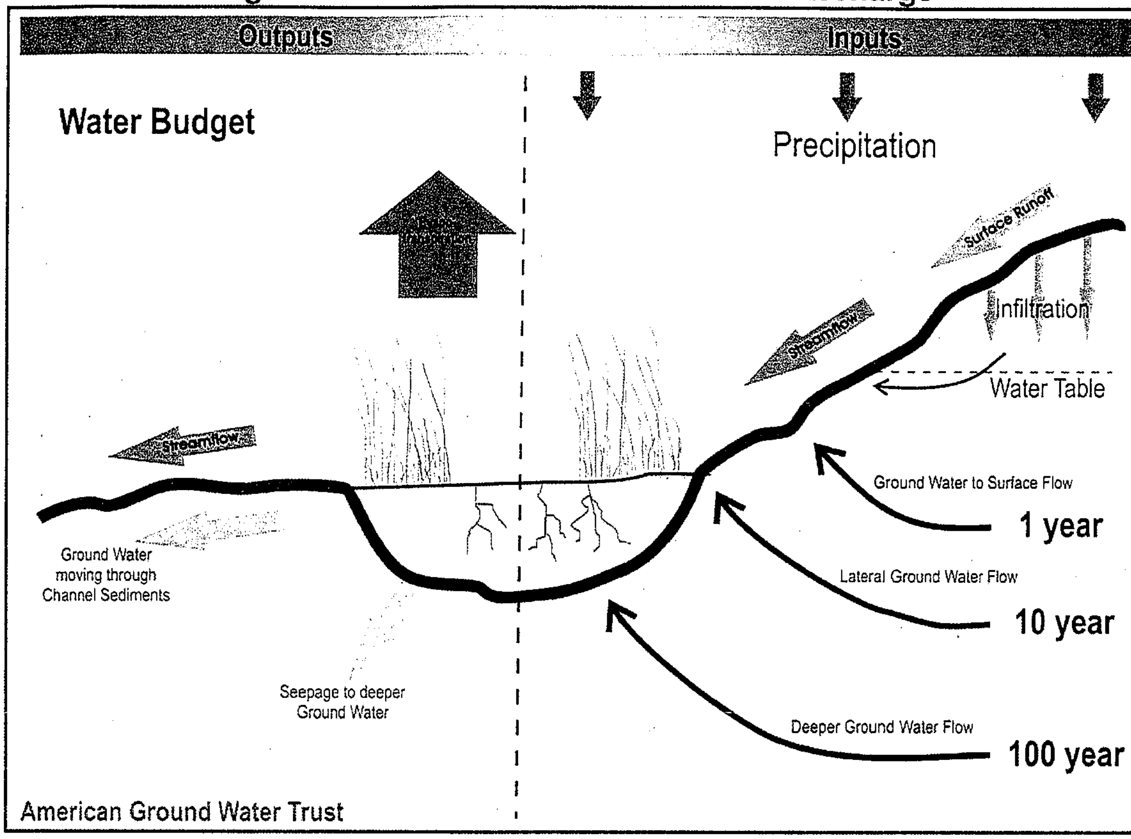
[7] Gordon et al., 1992.

Figure 4-5. Mechanism of Groundwater Recharge



4-5.1 **LID Infiltration Concepts.** Maintaining natural infiltration rates is an important aspect of LID design. Accomplishing this requires an accurate understanding of the existing soils and groundcover conditions. For example, a clay soil on a pre-development site may have very little infiltration capacity or a sandy soil, which is compacted, may have reduced capacity. The design should take care not to overload the hydraulic conductivity of existing soils.

Soil maps by themselves are not sufficient to determine the capacity of the soils to absorb and filter water; additional field testing is required. Dispersing flows, maintaining natural flow patterns, and directing flows towards soils with high capacities for infiltration will help maintain ground water levels. Amending soils by adding organic materials, reducing compaction by aeration, maintaining leaf or "duff" layers in natural areas, and reducing compaction requirements for non-load bearing areas will also enhance and maintain infiltration rates and patterns.

Although soils and natural areas have a high capacity to filter and treat pollutants, careful planning must take place to ensure that potential pollutants such as nitrates, oils, or other urban runoff contaminants are adequately treated before entering any potential water supply. Infiltration areas should not be located near areas that have potential for hazardous waste spills or contamination. It is important to ensure that runoff is adequately filtered before it is allowed to infiltrate, especially if local aquifers are particularly shallow. In cases where the water table is very high, it is often advisable to avoid infiltration altogether.

4-5.2 **Conventional Infiltration Concepts.** Conventional approaches concentrate on the infiltration capacity of a single end-of-pipe management facility such as a pond. Infiltration potential elsewhere on the site is often discounted or only analyzed for its effect on the flow of runoff into the facility. The conventional infiltration objective is to concentrate flows in one area and then utilize the infiltration capacity of the natural soil or conduits such as gravel. Natural groundwater flow patterns and recharge are often not considered. Conventional approaches may result in the elimination of critical volumes of flows to sensitive areas such as wetlands. Additionally, in many urban areas, the high loads of fine sediments to centralized facilities and the impacts of construction compaction can severely limit the infiltration capacity of the facility.

4-6 **EVAPOTRANSPIRATION.** Evapotranspiration is the loss of water from the ground by evaporation and transpiration. Evaporation is the return of moisture to the atmosphere from depressions, pond areas, or other surfaces. Transpiration is the return of water to the atmosphere through plants; moisture is absorbed by the roots and released through the leaves. The rate of evapotranspiration is dependent on air temperature, humidity, wind speed, sunlight intensity, vegetation type, and soil conditions.

4-6.1 **LID Evapotranspiration Concepts.** LID designs use open areas and vegetation to promote evapotranspiration. Larger areas used for evaporation, such as ponds, should have a flow regime that controls mosquito breeding. LID designs should not pond water for more than 72 hours as it may provide an opportunity for mosquitoes to breed. By keeping surface areas small and shallow, water can quickly evaporate and pollutants volatilize through plant uptake or evaporation.

LID designs also employ the capacity of vegetated areas to absorb, process, volatilize, and treat non-point source pollution as well as atmospheric pollution. Interception by leaves can significantly reduce the requirement for storage and infiltration. A mature canopy can intercept a significant number of small-volume, frequently occurring storms, absorbing precipitation into the plant leaves or evaporating precipitation from the leaf surface.[8] Additionally, uptake of soil moisture by plants helps to maintain the soil's capacity to absorb rainfall.

4-6.2 **Conventional Evaporation Concepts.** Conventional stormwater approaches are based on peak flow control over a short duration (usually 24 hours or less). For these single event designs, the evaporation process is often discounted or not considered.

[8] Sanders, 1986.

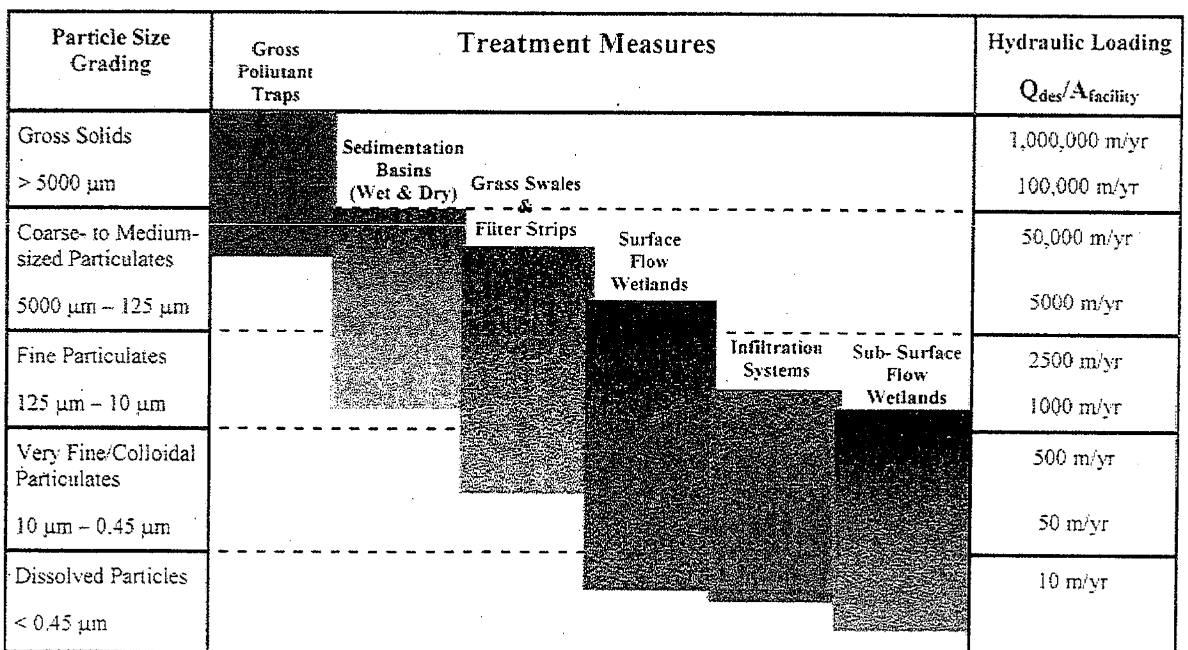
CHAPTER 5

LID DESIGN GOALS AND OBJECTIVES

5-1 **INTRODUCTION.** DoD facilities are faced with the responsibility of managing and protecting the natural resources of often large parcels of land reserved for many different functions. Uses can be intensive and can pose a variety of stormwater challenges. For example, a truck maintenance facility or post-exchange may generate stormwater pollutants and alter the downstream hydrology. Alternatively, a vehicle training range may pose a high risk for pollution (e.g., high TSS) but on an infrequent basis. There is no single management practice that can be universally applied to all drainage areas.

Figure 5-1 illustrates the removal effectiveness of various BMPs for a variety of pollutants. The graph illustrates the complexity of stormwater management; there is no single BMP or technique that can be used to effectively address all of the potential watershed issues.

Figure 5-1. Removal Effectiveness of Various BMPs



Source: Wong.

5-2 **REGULATORY AND NATURAL RESOURCE DESIGN ISSUES.** Many regulatory compliance or flood control (peak rate design) schemes for construction are designed to achieve only one objective (e.g., pre-development control for the 2-year 24-hour storm event). Regulations often fail to consider overall natural resource management, hydrologic objectives, and stewardship responsibilities of facilities.

Budget constraints often limit construction funding to that necessary for conveyance or flood control requirements. The limited framework may create situations where regulatory requirements are met but the design results in degradation of the natural resources. LID principles use hydrology as the integrating framework of design, and protect the overall ecology of the watershed. LID allows facilities to meet the regulatory requirement for flood control (by storing and infiltrating a sufficient volume) while sufficiently filtering targeted pollutants through natural and man-made systems.

5-3 **FUNDAMENTAL SITE PLANNING CONCEPTS.** The goal of LID site planning is to allow for full development and function of the intended site activity while maintaining the site's essential natural or existing hydrologic function. The LID site design process is sequential and iterative, and embraces the following five concepts:[9]

- Hydrology is the Integrating Framework for the Design
- Distribute Controls through Micromanagement
- Stormwater is Controlled at the Source
- Utilize Non-structural Systems Where Possible
- Create Multifunctional Landscape, Buildings and Infrastructures

5-3.1 **Hydrology is the Integrating Framework for the Design.** LID designs have the goal of mimicking the natural site drainage processes and functions. Techniques are used to modify hydrologic processes, such as infiltration or storage, to meet the specific water quality, water quantity, and natural resource objectives. LID designs create an effective drainage process for stormwater on the site. A stormwater management system will come closest to mimicking natural flow patterns when storage and infiltration components are distributed across the site.

5-3.2 **Distribute Controls Through Micromanagement.** In order to emulate natural processes, it is imperative to view the site as a series of interconnected small-scale design controls. Such a structure creates opportunities for redundancy in treatment and control, the development of a "treatment train" for water quality control, and the opportunity to strategically locate LID components.

5-3.3 **Stormwater is Controlled at the Source.** Controlling and treating runoff as it is being generated reduces or eliminates the risks associated with transporting pollutants further downstream through pipes and channels. Management of stormwater at the source is especially valuable if remediation is required, such as in the case of an accidental spill of pollutants, because the problem can be easily isolated or the treatment system adjusted.

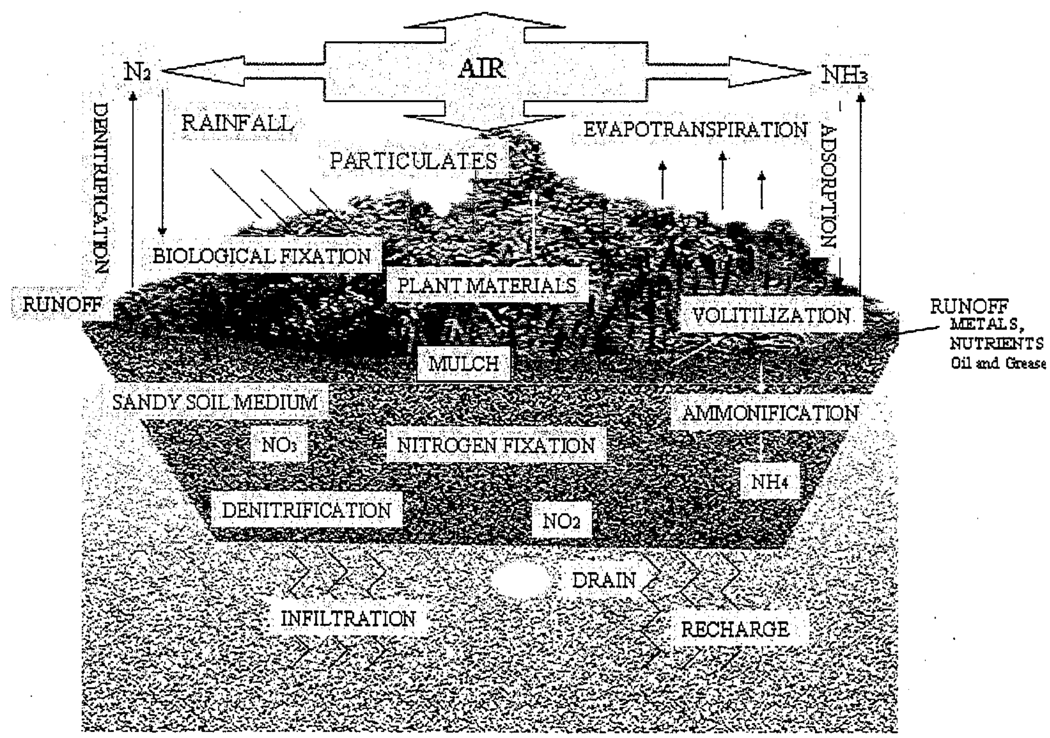
5-3.4 **Incorporate Non-Structural Systems.** LID designs recognize the potential of natural systems to intercept and filter pollutants. Phytoremediation techniques that

[9] PGDER, 2000a.

take advantage of the biological and chemical processes of the plant soil complex have shown tremendous potential in stormwater management. These natural systems are easy to design, construct, and maintain, even though the naturally occurring filtering and treatment processes may be quite complex and multidimensional. Benefits of using these small-scale and simplified systems (such as soil amendments, landscaping, or re-vegetation) include the reduced need for costly large-scale construction projects (such as underground concrete vaults or proprietary filters).

Figure 5-2 illustrates the range of biological and chemical processes that have been documented to occur in a bioretention cell. The bioretention cell is a landscape area constructed of specialized soil and plants that can effectively absorb and treat urban runoff.

Figure 5-2. Biological and Chemical Processes that Occur in a Bioretention Cell



Source: Prince George's County, Maryland Department of Environmental Resources (PGDER), 2000.

5-3.5 **Utilize Multifunctional Landscape, Buildings and Infrastructures.** There are a wide variety of LID practices available. The primary criterion in selecting LID practices is that the design of the component contributes to satisfying the design and regulatory objectives. Design features are often multifunctional and satisfy multiple objectives. The development of vegetated roofs is a good example. A vegetated roof can reduce the effects of atmospheric pollution, reduce runoff volume and frequency, reduce energy costs, create an attractive environment, and have reduced replacement and maintenance, and longer life cycle costs. There are many types of vegetated roofs that can be developed including pre-made grids, or cells, or whole systems.

5-4 **LID MANAGEMENT AND DESIGN STRATEGIES.** LID design is an iterative process that requires a thorough understanding of the management objectives, a detailed understanding of the physical and natural resources of the site, a conceptual site design that can be refined to achieve the goal of a hydrologically functional landscape, and a long-term maintenance plan.

5-4.1 **LID Site Planning Components.** This section presents the aims of LID site planning and, in light of existing site development requirements, describes how LID site design can be best approached to manage runoff.

5-4.1.1 **Hydrologic and Hydraulic Objectives.** The purpose of LID site planning is to significantly maintain the predevelopment runoff volume and flow rate. Ideally, and where site conditions allow, this will be achieved in a way that replicates the site's predevelopment hydrologic functions. Sites that are characterized before development by porous soils, substantial vegetative ground cover, and ungraded topography naturally perform several important hydrologic functions:

- Facilitate infiltration, evapotranspiration, retention and detention of runoff
- Limit runoff flow rates because of ground surface roughness
- Help control water quality through surface and subsurface filtering of pollutants and sediments

On a developed site, these hydrologic functions can continue to be provided by the preservation of natural features or construction of a variety of man-made features (as described in Chapter 9). Taken together, the utilization of these features comprises a distributed source control strategy that is designed to not only meet regulatory requirements but also to provide superior natural resource protection.

Maintaining areas with high soil porosity, vegetative ground cover, and shallow ponding will help meet the following objectives:

- Flood control. Facilitating the infiltration of runoff and decreasing overland flow rates reduces the risk of flooding in receiving waters. To meet design objectives and regulatory requirements completely, supplemental controls may still be required.
- Volume Control. The overall volume of runoff that leaves a site is kept as close as possible to predevelopment levels.
- Peak Control. The peak runoff rate does not increase above predevelopment levels, and the entire runoff hydrograph emulates the predevelopment hydrograph.

- Filtering and Treatment of Pollutants. Runoff is directed across vegetated areas and through porous media to provide significant reductions in the concentration of sediments and pollutants in the water.

- Groundwater Recharge. Infiltration is expedited to enhance groundwater recharge rates and help sustain base flows in nearby streams.

5-4.2 **LID Design Approach.** The LID approach to site design seeks to maintain or restore the hydrologic impacts of site development using a combination of runoff management strategies, site design techniques, and distributed source controls (IMPs). LID design requires that site plans address the overall natural resource and compliance issues within the watershed. The long-term success of this approach requires an understanding of the maintenance requirements and life-cycle effectiveness of the LID practices and the development of an appropriate maintenance and pollution prevention plan for the facility.

While the influence of each of the components of the design process varies from site to site, a general process has been developed to ensure that all of these components are considered. Although the preference in LID design is to reduce the hydrologic impacts on the site and to retain naturally effective hydrologic features, it is recognized that significant impacts may occur because of the nature of DoD activities. When compensating features are required, LID emphasizes the use of integrated site features that control runoff as close as possible to the source, rather than transporting pollutants and attempting to mitigate for lost functions elsewhere. Figure 5-3 illustrates the general flow of the design process.

Figure 5-3. LID Design Process

Conserve Natural Areas
↓
Minimize Development Impacts
↓
Maintain Watershed Timing
↓
Provide IMPs
↓
Manage for Pollution Prevention

Source: PGDER.

This approach is often an iterative process that requires several attempts to balance all of the design components in the most economical and environmentally effective way. Described below are the individual design components.

5-4.2.1 **Conservation of Natural Areas.** LID is a stormwater management strategy that addresses the overall regulatory and resource protection goals of a site in a watershed context. Because development typically occurs incrementally, this approach will allow for adjustments or modifications to site design strategies and techniques to reflect dynamic resource protection and regulatory issues. Communities and bases often have extensive watershed management and natural resources conservation goals; master plans identify sensitive environmental areas and preservation areas such as wetlands, mature woods, and habitats. The LID site design should address any potential impacts to these areas and encourage conservation of these areas within the site. Examples of conservation include:

- Preserving a forest corridor that connects with an existing stream valley
- Maintaining flow volume and discharge rates to offsite wetlands
- Incorporating buffers around sensitive habitat areas

5-4.3 **Minimization of Development Impacts.** Within the portion of the site selected for the placement of roads, buildings, and other development activities, minimal disturbance techniques (site fingerprinting) can be used to avoid soil compaction, retain mature trees, and limit the environmental impact of staging areas. Examples of minimal disturbance techniques include:

- Delineating and flagging the smallest site disturbance area possible
- Minimizing the size of construction impacts or offsite easements and property acquisition
- Minimizing the size of material storage areas during and after construction
- Maintaining flow patterns

5-4.4 **Control of Watershed Timing and Runoff Patterns.** Maintaining the site's natural runoff control areas and restricting building over the site's more pervious soils will help keep the infiltration capacity of the site close to predevelopment levels. Maintaining the watershed timing of a site is also important. The cumulative effects of decreasing the post-development watershed times of concentration of several sites can have a significant impact on downstream habitat. It is also desirable to maintain natural vegetation in steeply sloped areas and to retain natural drainage divides. This will encourage dispersed flow paths and, consequently, help reduce the development of channels that lead to erosion and flooding problems.

Adequate drainage from buildings, walkways, and roads must be provided. Traditional designs often create a drainage system that has the effect of increasing the rate at which runoff moves into receiving waters during storm events. In turn, this produces a higher volume of runoff, a higher peak rate of flow, and an earlier runoff event than would occur under less developed conditions. The opportunity for groundwater recharge is eliminated, because infiltration into swales and grassed areas cannot effectively occur if runoff passes through quickly.

The overall grading objective for LID is to provide a surface landform that will distribute flows in a shallow and slow moving pattern toward areas where the infiltration capacity is highest. Examples of LID techniques to control rates of runoff and watershed timing include:

- Use flatter rather than steeper grades, provided that adequate drainage for buildings and traffic is maintained
- Reduce the height of slopes, to prevent runoff from gaining speed as it moves downhill
- Where flow begins to accumulate, increase the length of flow paths, diverting and redirecting the flow, preferably with vegetated features
- Minimize use of curb and gutter systems and piped drainage systems in favor of grassed swales
- Minimize the amount of impervious area used for pavement
- Disconnect impervious areas by directing runoff from buildings and pavements onto lawns or other vegetated areas, keeping flow velocities at a level that will not cause erosion
- Preserve naturally vegetated areas and existing topography in places where these help slow runoff and encourage infiltration
- Use weirs and check dams in swales

5-4.5 **Use of Integrated Management Practices (IMPs).** Once all of the design strategies and techniques have been implemented, IMPs are selected to achieve the site water quality and quantity objectives. IMPs are distributed, multifunctional, small-scale controls, selected based on their ability to achieve the site design water quality and quantity objectives in a cost effective manner. IMPs are not a "one-size-fits-all" approach. For example, using amended soils to filter and store runoff may be appropriate for a rural road section with high traffic but inappropriate next to a parking area that may be subjected to compaction from overflow parking or vehicle movement. More details on IMPs and their selection are found in Chapter 8.

5-4.6 **Pollution Prevention.** The goal of pollution prevention is to reduce, reuse and recycle a variety of pollutants before they become environmental problems. The final step of the LID design approach is to incorporate programs that keep pollution out of runoff in the first place and, consequently, to increase the longevity of the IMPs. Reduction of fertilizer, pesticide and herbicide use and the implementation of regular street sweeping are some common pollution prevention activities.

NAVY: Pollution Prevention (P2) is one of the four pillars of the Navy's Environmental Quality Initiative (EQI). EQI aims to use P2 to attain environmental compliance, while minimizing life cycle costs. Rather than promoting pollution prevention because it is desirable from an environmental standpoint, EQI uses pollution prevention to minimize the cost of environmental compliance. For example, building a bioretention cell to treat runoff from a parking lot before discharge into a stream is a much more efficient and cost effective alternative to discharging directly into the stream and paying for stream restoration later.

AIR FORCE: Air Force Instruction (AFI) 32-7080 lays the framework for P2 implementation. Compliance by all Air Force installations is required. Air and water pollutant reduction is one of the six P2 program elements. P2 is mandated at the Major Command (MAJCOM) level, and the Air Force Center for Environmental Excellence is the primary provider of P2 technical support services. Installations must implement P2 management plans and conduct regular P2 opportunity assessments, which should be based on existing waste stream management plans when they exist.[10]

ARMY: P2 is a required element in the Army's Sustainable Project Rating Tool (SPiRiT); compliance with SPiRiT is now mandatory for MILCON construction projects. P2 plans for Army installations are developed from opportunity assessments of existing waste stream data and are designed to maximize environmental compliance. The U.S. Army Environmental Center provides P2-related technical and policy assistance.

5-5 DESIGN GUIDANCE AND STANDARDS

5-5.1 **Methods to Determine Effectiveness.** Stormwater projects are typically designed with a particular objective in mind, such as flood control or water quality improvement. Such projects typically require that the designer evaluate the effectiveness of the proposed treatments at meeting the stated objectives.

A number of hydrologic models have been developed to model surface runoff from a given drainage area. Because conventional models are primarily concerned with computing flow rates or flood hydrographs at a point of interest, this approach to hydrologic analysis must be modified in cases where not all of the runoff from a given site converges to a single point. Typical watershed models take into account general land cover and stream channel characteristics. To account for LID features and runoff management devices, refinement of the analysis may be desirable. A variety of tools are freely available from public agencies:

5-5.1.1 **Natural Resources Conservation Service (NRCS).** The NRCS, formerly called the Soil Conservation Service, has been developing runoff models for decades. The NRCS models TR-20 and TR-55 account for variations in land cover and the velocity of water movement across a watershed. Of particular interest are the determination of a drainage area's curve number (CN) and time of concentration (T_c). The value of CN reflects the degree to which land surface conditions will generate runoff, while the value of T_c indicates how quickly the runoff will converge at a particular point downstream. TR-20 and TR-55 are popular for watershed modeling but are generally not recommended for predicting runoff from small storms.

5-5.1.2 **Federal Highway Administration (FHWA).** The FHWA has developed a variety of software packages, primarily concerned with channel and pipe hydraulics.

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[10] Air Force, 1994.

These programs are most useful in those areas where detailed analysis of flow behavior based on predetermined flow rates is required.

5-5.1.3 **Hydrologic Engineering Center of the U.S. Army Corps of Engineers (HEC).** The Hydrologic Engineering Center of the U.S. Army Corps of Engineers actively maintains a suite of tools for modeling surface water hydrology and hydraulics.

5-5.1.4 **EPA.** The EPA maintains the Storm Water Management Model (SWMM) that performs simulations of both water quantity and quality for urban runoff events.[11] In late 2002, EPA extensively revised SWMM to include more detailed analysis of small-scale stormwater management devices. The SWMM algorithm is able to explicitly simulate storage and, therefore, is particularly appropriate for simulating discrete LID systems. Obtaining reasonable estimates of storage parameters needed in SWMM is of critical importance. Creative adaptations of SWMM may be necessary because the model does not directly model runoff from an impervious surface onto a pervious one.

5-5.1.5 **Prince George's County, Maryland.** The Prince George's County Department of Environmental Resources – Programs and Planning Division, working with Tetra Tech, Inc., has developed a BMP evaluation module to assist in assessing the effectiveness of LID technology. This module uses simplified process-based algorithms to simulate BMP control of modeled flow and water quality time series generated from runoff models such as the Hydrologic Simulation Program, FORTRAN (HSPF). These simple algorithms include weir and orifice control structures, storm swale characteristics, flow and pollutant transport, flow routing and networking, infiltration and saturation, evapotranspiration, and a general loss/decay representation for pollutants. It offers the user the flexibility to design retention style or open-channel BMPs, define flow routing through a BMP or BMP network, simulate IMPs such as reduced or discontinuous impervious surfaces through flow networking, and compare BMP controls against a defined benchmark such as a simulated pre-development condition. Because the underlying algorithms are based on physical processes, BMP effectiveness can be evaluated and estimated over a wide range of storm conditions, BMP designs, and flow routing configurations. Such a tool provides a quantitative medium for assessing and designing TMDL allocation scenarios and evaluating the effectiveness of a proposed management approach.

Five basic design aspects were used to develop the methodology for the module. They are: (1) the incorporation of input runoff data, (2) design and representation of a site plan, (3) configuration of BMPs of various sizes and functions, (4) schematic representation of flow routing through a network of BMPs, and (5) evaluation of the impact of a site design with BMPs. The module interface is the platform for an interactive linkage between each of the five design features of the module.

5-5.1.6 **Commercial Sources.** In addition to the freely available models, there are a variety of commercial models on the market. Information about these other tools can be found on the Internet.

[11] EPA, 1983.

5-5.2 **Monitoring Strategies.** A variety of techniques are available to monitor the effectiveness of LID features for managing water quantity and quality. A well-implemented monitoring program will be valuable not only for the purpose of local runoff management objectives, but can also provide useful information to the Engineering Service Center, which is developing a web-based expert system.

5-5.2.1 **Water Quantity Monitoring.** The effectiveness of LID in controlling runoff volume and peak flow rates can be monitored either at individual features on a site or at some selected point downstream where flow paths converge and a measurement device can be installed.

5-5.2.1.1 **Small Scale.** On a small scale, both manual and automatic sampling methods can be used to calculate flow rates upstream and downstream of an LID installation, based on the depth measured using a weir or a rate of flow measured using a conveyance device.

5-5.2.2 **Large Scale.** On a larger scale, where LID features are used as retrofits in developed areas, the effectiveness of the retrofits can be assessed by comparing pre-LID and post-LID flow rates downstream. Using these data and some straightforward hydrologic calculations, a characteristic hydrograph can be developed to evaluate the site's response to storm events resulting from the implementation of LID treatments. Data from stream gages should indicate that runoff from smaller storms has decreased after LID implementation. As more LID features are used for stormwater retrofits on a site, the decrease in runoff will become more significant.

5-5.2.3 **Water Quality Monitoring Parameters.** The effectiveness of a runoff management feature can be evaluated using the flow through the feature, the quality of the receiving waters, or both. The Nationwide Urban Runoff Program (NURP) has identified the following "standard pollutants characterizing urban runoff:"[12]

Table 5-1. Standard Pollutants in Urban Runoff

Pollutant	Abbreviation
Suspended Solids Concentration	SSC
Biochemical Oxygen Demand	BOD
Chemical Oxygen Demand	COD
Copper	Cu
Zinc	Zn
Total Phosphorous	TP
Soluble Phosphorus	SP
Total Kjeldahl Nitrogen	TKN

[12] Ibid.

Nitrate + Nitrite	$NO_2 + NO_3$

5-5.2.4 **Biological Monitoring.** Pollutants in stormwater runoff have a direct effect on the biological integrity of the receiving waters. The effectiveness of water quality controls can therefore be evaluated by assessing the biological health of the receiving waters in the vicinity of the stormwater outfall. The EPA has developed Rapid Bioassessment Protocols (RBP)[13] that can be used to characterize the existence and severity of impairments to streams, and help to identify sources and causes of impairment.

5-5.2.5 **Monitoring Program.** There are four phases to develop a monitoring program:[14]

1. Determine the objectives and scope of the monitoring program
2. Develop the monitoring plan in view of the objectives
3. Implement the monitoring plan
4. Evaluate and report the results

Monitoring programs are shaped by the site characteristics, the goals of the project, regulatory requirements, and available funds.

5-5.2.6 **Variability.** The high variability of stormwater flows and pollutant concentrations at any location makes it difficult to obtain useful monitoring results. Typically, facilities must collect a large number of samples to adequately characterize how a device is functioning under natural conditions. The monitoring approach used on any given site will depend on regulatory requirements, the pollutants of concern, the physical characteristics of the runoff management features, and the availability of funds and personnel for planning, sampling and analysis.

5-5.2.7 **State and Local Program Conformance.** Water quality monitoring programs should be undertaken to conform to state and local protocols. A detailed guidance manual for water quality data collection, management and interpretation is available from the Environmental Protection Agency[15] and the Department of Transportation.[16] The guidelines, which are primarily concerned with meeting the national stormwater BMP database requirements, can be easily adapted for use in a variety of monitoring activities.

5-5.2.8 **Sampling Locations.** An effective monitoring effort for decentralized runoff management requires a judicious selection of sampling locations as well as sampling times and techniques. The challenge is often to complete the monitoring effort

[13] Barbour et al., 1999.
[14] DOT, 2000; EPA, 2002.
[15] EPA, 2002.
[16] DOT, 2000.

effectively under budget constraints. If the site design includes many LID features, sampling only a few may provide a reasonable basis to estimate the effectiveness of the full suite of features.

5-5.2.9 **Sampling Protocols.** Monitoring protocols vary depending on the expected chemical composition of the runoff, the pollutant of concern, the desirability of monitoring the effectiveness of a device at a given location, and the importance of assessing water quality at points downstream. As sampling data is collected over time, trends in the water quality become apparent. Adjustments in the monitoring plan may be appropriate to ensure that across the site samples are not taken any more or less frequently than necessary to ensure that a desirable level of water quality is maintained.

CHAPTER 6

DISTRIBUTED MICRO-SCALE SYSTEMS

6-1 **INTRODUCTION.** In addition to land surface strategies, LID practices include incorporating small landscaped features and manufactured devices into a site. The management of runoff as it is generated reduces the need for management further downstream. Small distributed systems can perform several important runoff management functions:

- Increase rates of infiltration
- Slow down runoff, reducing flow rates from the site and increasing time for infiltration
- Add retention (the amount of water stored at the surface for the duration of the storm event)
- Add detention, which causes water to be restrained temporarily before it moves further downstream
- Improve water quality by filtering pollutants through media

6-2 **REPRESENTATIVE LID PRACTICES.** LID uses design components (IMPs) that can be selected and customized for specific stormwater management objectives. The selective use and customization of these components will involve a variety of standards and specifications for construction and maintenance. Described below is a collection of LID practices and their design, construction and maintenance characteristics.

Distributed micro-scale systems can include, but are not limited to:

- Soil amendments
- Bioretention
- Dry Wells
- Filter Strips
- Vegetated Buffers
- Grassed Swales
- Infiltration Trenches
- Inlet Pollution Removal Devices
- Rain Barrels and Cisterns

- Tree Box Filters
- Vegetated Roofs
- Permeable Pavers

Table 6-1 presents the variety of runoff management functions provided by these features. A more detailed description and design approach for these features is provided in Chapter 8.

Table 6-1. Functions of LID Features

Feature	Effect or Function				
	Slower Runoff	**Infiltration**	**Retention**	**Detention**	**Water Quality Control**
Soil Amendments		X			
Bioretention		X	X	X	X
Dry Wells		X	X		X
Filter Strips	X				X
Vegetated Buffers	X				X
Grassed Swales	X				X
Infiltration Trenches		X			X
Inlet Devices					X
Rain Barrels			X		
Cisterns			X		
Tree Box Filters					X
Vegetated Roofs	X			X	X
Permeable Pavers		X			X

6-2.1 **Nutrient Processing.** Surface water runoff in urban areas can include significant quantities of chemical nutrients, particularly nitrogen and phosphorous. When these nutrients reach local water bodies, they can contribute to eutrophication. (Eutrophication is a naturally occurring process in which nutrients accumulate in a body of water over time; the term is often used to signify acceleration of this process by human activity.) Several of the LID components described in this UFC (see Chapter 8) filter out these nutrients to various degrees of effectiveness, depending on the design. LID approaches that utilize vegetation not only filter nitrogen and phosphorous out of the water and into the soil, but also make these nutrients available to the plants to form plant tissue.

6-2.2 **Treatment Train Approach to Water Quality.** Following a typical flow path beginning where runoff is generated from an impervious area, runoff water quality control can be implemented in the following steps:

1. Minimization. Design the site to treat pollutants effectively in small quantities, rather than allow larger quantities of runoff to accumulate before treatment.

2. Natural Filtration. Use the physical, chemical and biological processes of vegetation and soils to filter pollutants.

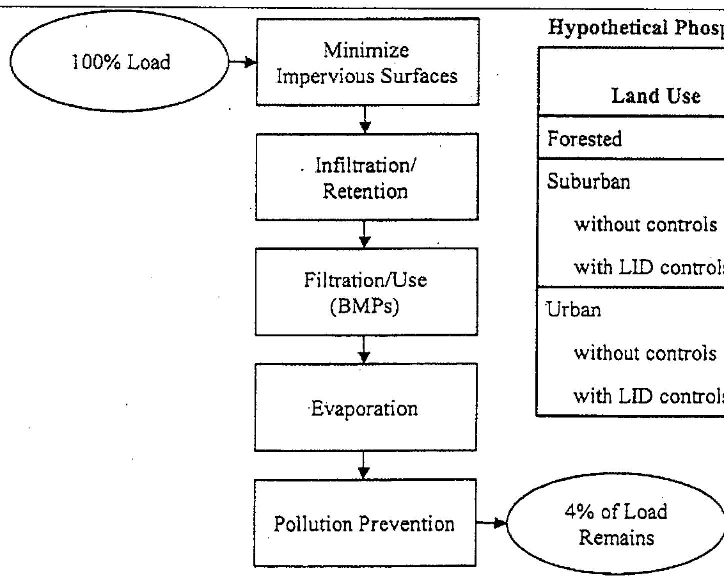
3. Constructed Filtration. Use the physical, chemical and biological processes of distributed micro-scale systems to filter pollutants.

4. Evaporation. Store and evaporate water in shallow depressions so that particulates can be removed.

5. Pollution prevention. Incorporate management practices such as restricted fertilizer use and diligent street sweeping to reduce pollutant loads. (Note that while the first four steps above pertain to site features, this final step pertains to post-construction maintenance).

Figure 6-1 shows a typical treatment train process for phosphorus removal.

Figure 6-1. Treatment Train Process for Phosphorus Removal



Hypothetical Phosphorus Reductions

Land Use	Pollutant Load (lb/ac/yr)
Forested	0.18
Suburban	
without controls	0.58
with LID controls	0.023
Urban	
without controls	1.82
with LID controls	0.073

Source: Adapted from PGDER.

6-2.3 **Energy Processing.** LID features that incorporate vegetation can help to moderate high ambient air temperatures. Even on a small scale, vegetation will have a local cooling effect. Vegetation can be selected and placed to improve shading, or to provide a buffer against winds. Using vegetated roofs can result in significant energy savings in the operation of a building's air conditioning system.

6-2.4 **Multifunctional Infrastructure and Buildings.** Some LID features can simultaneously provide a variety of hydrologic functions. A bioretention area, for example, can filter runoff for quality control, detain it, and infiltrate the stormwater into the ground. Similarly, vegetated roofs on buildings reduce runoff, reduce pollutants in both the water and the air, and moderate the internal building temperature.

6-2.5 **Ancillary Benefits.** This UFC describes LID primarily in terms of hydrologic impacts. LID runoff management strategies can also contribute to an aesthetically pleasing landscape, increasing the value of the property where these strategies are employed. In a variety of completed projects, micro-scale runoff management features have provided architectural interest in various forms, such as employing berms in otherwise open spaces, rainwater channels along pedestrian streets, fountains fed by intermittent stormwater, and bioretention areas that attractively subdivide large parking lots. The visibility of these features also provides opportunities for citizens and property owners to become more aware of the importance of stormwater in our urban environment.

CHAPTER 7

COMPARISON OF LID TO CONVENTIONAL PRACTICES

7-1 **INTRODUCTION.** Conventional stormwater management practices focus on providing an efficient site drainage system that rapidly conveys runoff away from buildings and off pavement, and then attenuates the peak runoff rate at a large stormwater management facility downstream. In contrast, LID provides runoff management as far upstream as possible – where it originates – and if necessary, also at multiple points along each flow path. LID and conventional practices can be further compared in a variety of ways:

7-2 **COMPLIANCE VS. WATER RESOURCE OBJECTIVES.** While conventional stormwater management is primarily concerned with attenuating the peak runoff rate from a developed site, the principal goal of LID is to ensure maximum protection of the ecological integrity of the receiving waters by maintaining the watershed's hydrologic regime.

7-3 **WATER QUANTITY CONTROL.** Conventional drainage practices effectively reduce peak runoff rates, but do not reduce runoff volume. Instead, conventional drainage practices increase runoff volume by not mitigating the effects of the increased impervious area. The LID features that facilitate infiltration, by comparison, help to reduce runoff volume directly. Runoff volume reductions using LID features can be significant when infiltration is increased over a sufficiently large area.

Conventional drainage reduces the amount of subsurface water available to the base flow in nearby streams. LID features that enhance infiltration can have the beneficial effect of helping to maintain those base flows. Other LID features allow the strategic use of stormwater on-site, while conventional drainage designs focus on moving the water rapidly off-site.

A conventional stormwater management facility has a limited ability to manage water quality because it is limited to removal by settlement of pollutants. An LID approach, by comparison, takes advantage of a variety of mechanisms that filter water either overland or via infiltration to the subsurface.

7-4 **CONSTRUCTION COSTS.** Construction costs for LID will vary depending on the characteristics of predevelopment site features, the density of development, the particular LID features selected, and their size and design. For example, the cost of bioretention areas will be a function of the depth of porous backfill and the degree to which underdrains are utilized. Case studies for commercial, townhouse, and detached home residential areas in Prince George's County, Maryland, have demonstrated that LID site design costs can compare favorably with conventional approaches.[17] Costs are not simple to generalize. The scale of the project, availability of materials, and skills and training of staff are all factors. IMPs involving landscaped areas are often simple to maintain because work can often be performed by landscaping crews or residents; hard

[17] Greenhorne and O'Mara, 1998.

structures, such as permeable paving systems with underdrains, may require more specialized maintenance.

7-5 **OPERATION AND MAINTENANCE.** Regular inspections of conventional stormwater management facilities are required to ensure that the storage volume has not been reduced by sediment, outlets are not clogged by debris, and structural features maintain their integrity. For a site designed using an LID approach, runoff management features will tend to be higher in number and several types of features (e.g., bioretention areas) need to be maintained by the property owner. The maintenance of these LID features is straightforward and can easily be performed as part of regular landscaping. Other LID features typically employed along public streets (such as tree filters) require more specialized maintenance to ensure that the filter media are not clogged and toxic materials such as heavy metals do not accumulate to a level at which they become a health hazard.

7-6 **RETROFIT POTENTIAL.** Retrofitting an already developed area with a conventional stormwater management system requires a considerable amount of space and is likely to involve extensive site disturbance. The LID micro-scale systems listed in the previous chapter require less site disturbance for each installment. LID retrofits may be much easier than conventional retrofits on sites where intensive development has already occurred. Locating sites for installing small devices is far easier than finding a large site for a stormwater management facility. LID retrofits can be customized to pollutant loads, allowing more complete control over pollutant removal.

CHAPTER 8

INTEGRATED MANAGEMENT PRACTICES

8-1 **INTRODUCTION.** This chapter gives an overview of several of the most common and well-researched integrated management practices (IMPs) currently in use. Information is given on appropriate use, typical cost, maintenance needs, and commonly required corrective actions. This information is meant to facilitate the selection of IMPs appropriate for individual situations. This chapter is not exhaustive: many other IMP types are in use or are under development. Evaluation of other practices is left to the facility and regulatory agencies.

8-1.1 **Most Appropriate Uses.** This section outlines how each of the IMPs should be incorporated into a site plan.

8-1.2 **Cost Data.** Cost data is given in 2003 U.S. dollars, except where noted. All costs are estimates, and are given in broad ranges. These represent only initial costs and do not account for life cycle costs such as maintenance. These cost estimates are to be used for general planning purposes, not to create accurate project budgets.

8-1.3 **Maintenance Issues.** This section highlights some of the maintenance requirements of the IMPs. It is meant to give a general sense of the maintenance intensity of each of the technologies.

8-1.4 **Corrective Actions.** This section highlights some of the common problems associated with each of the IMPs.

8-2 **SOIL AMENDMENTS.** Soil amendments, which include both soil conditioners and fertilizers, make the soil more suitable for the growth of plants and increase water retention capabilities. The use of soil amendments is conditional on their compatibility with existing vegetation, particularly native plants.

Figure 8-1. Southern Maryland Wood Treating Site: On-site Thermal Desorption of Contaminated Soils. Final Grading and LeafGro® Placement

Source: EPA.

8-2.1 **Most Appropriate Uses.** Soil amendments increase the soil's infiltration capacity and help reduce runoff from the site. They have the added benefit of changing physical, chemical and biological characteristics so that the soils become more effective at maintaining water quality.

8-2.2 **Cost Data.** Compared to the costs of traditional lawn preparation practices, enhancing native soil with soil amendments may have increased upfront costs. However, the cost of using amended soils can be at least partially offset by reductions in the required volume of stormwater ponds or other detention or retention practices. Tilled Compost-Amended Turf (TCT) practices, besides requiring greater site preparation, require larger volumes of material to be delivered to the site as well as methods to ensure that the amendments are well mixed with the existing soil.[18] The following cost estimates are based upon 1996 prices in the Seattle, Washington metropolitan area. Potential soils analysis costs are not included, but can cost as much as $125 per sample.

Table 8-1. Costs Associated with Soil Amending[19]

Component	Average Cost (1996 U.S. dollars)
Soil and Site Preparation	61¢ per square foot
Soil Amendments	$16 per cubic yard
Blower Application	5¢ to 10¢ per square foot

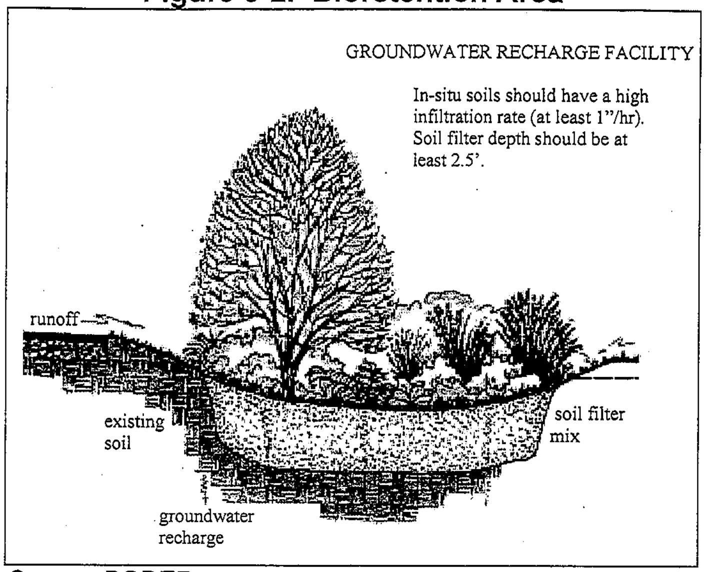
8-2.3 **Maintenance Issues.** In some jurisdictions across the country, soil amendments may be inspected as part of the sediment control plan for a site, usually upon site completion. Routine inspection of amended soils should evaluate factors that may affect the soil's infiltration capacity, aeration and organic content. Typical post construction concerns include areas subject to compaction, hydric or waterlogged soils, poor cover conditions, increased development, and a decrease in organic content. In addition, a routine soil infiltration rate analysis of amended soils in potential problem areas is recommended.

8-2.4 **Corrective Actions.** Corrective actions for soil amendments involve restoring the infiltration capacity of the soil. Reductions in infiltration capacity typically result from compaction or extensive root matting of groundcovers, such as grasses. The first step of corrective action should be extensive mechanical aeration. If this does not restore the infiltration rate, organic amendments should be disked into the soil for a depth of several inches and the site restabilized.

8-3 **BIORETENTION.** Bioretention areas typically have porous backfill under the vegetated surface, and an underdrain that encourages infiltration and water quality filtering while avoiding extended ponding.

[18] Chollak and Rosenfeld, 1998.
[19] Ibid.

Figure 8-2. Bioretention Area



Source: PGDER.

8-3.1 **Most Appropriate Uses.** Bioretention features are used to treat stormwater that has run over impervious surfaces in commercial, residential, and industrial areas.[20] Use of bioretention for stormwater management is ideal for median strips, parking lot islands, and swales.

8-3.2 **Cost Data.** Construction cost estimates for a bioretention area are slightly greater than for required landscaping at a new development.[21] Commercial, industrial and institutional site costs range between $107 and $430 per square meter ($10 and $40 per square foot,) based on the need for control structures, curbing, storm drains and underdrains.

8-3.3 **Maintenance Issues.** Routine maintenance should include a biannual health evaluation of the trees and shrubs and subsequent removal of any dead or diseased vegetation.[22] This maintenance can be incorporated into regular maintenance of the site landscaping. If the bioretention feature is located in a housing development, the maintenance responsibility could be delegated to the residents. The use of native plant species in the bioretention cell will reduce fertilizer, pesticide, water, and overall maintenance requirements.

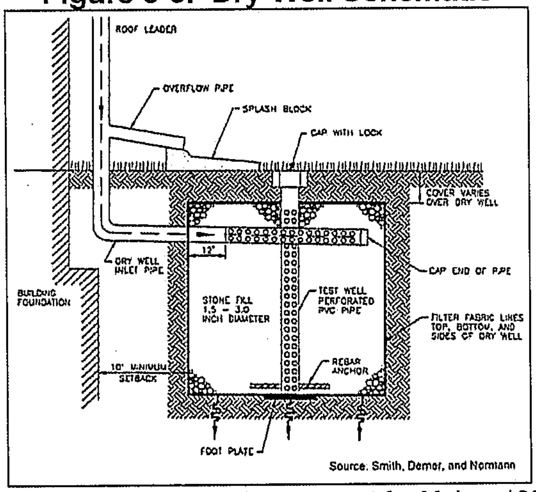
8-3.4 **Corrective Actions.** Treat diseased vegetation as needed using preventative and low-toxic measures. When levels of pollutants reach toxic levels that impair plant growth and the effectiveness of the BMP, soil replacement may be

[20] EPA, 1999a.
[21] Ibid.
[22] Ibid.

required.[23] Other potential tasks include replacement of dead vegetation, soil pH regulation, erosion repair at inflow points, mulch replenishment, unclogging the underdrain, and repairing overflow structures. Depending on pollutant loads, soils may need to be replaced within 5-10 years of construction.[24]

8-4 **DRY WELLS.** A dry well typically consists of a pit filled with aggregate such as gravel or stone and is located to catch water from roof downspouts or paved areas.

Figure 8-3. Dry Well Schematic



Source: Stormwater Management for Maine, 1995.

8-4.1 **Most Appropriate Uses.** Dry wells are suitable for treating small impervious areas (as an alternative to infiltration trenches) and may be useful on steeper slopes where trenches or other facilities cannot be installed. Dry wells are particularly suited to treat runoff from residential driveways or rooftop downspouts. It is important to avoid installation in large areas with high sediment loads and in soils with limited permeability. Dry wells are not appropriate for treating runoff from large impervious surfaces such as parking lots.

8-4.2 **Cost Data.** Costs for dry wells are site specific. Cost is determined by the cost of excavation and the price of gravel. This will depend on the well volume and the source of the gravel.

8-4.3 **Maintenance Issues.** Dry wells are typically employed in single-family homes; maintenance is usually the responsibility of the homeowner. Maintenance is minimal and includes clearing the rain gutters of debris that clogs the downspout.

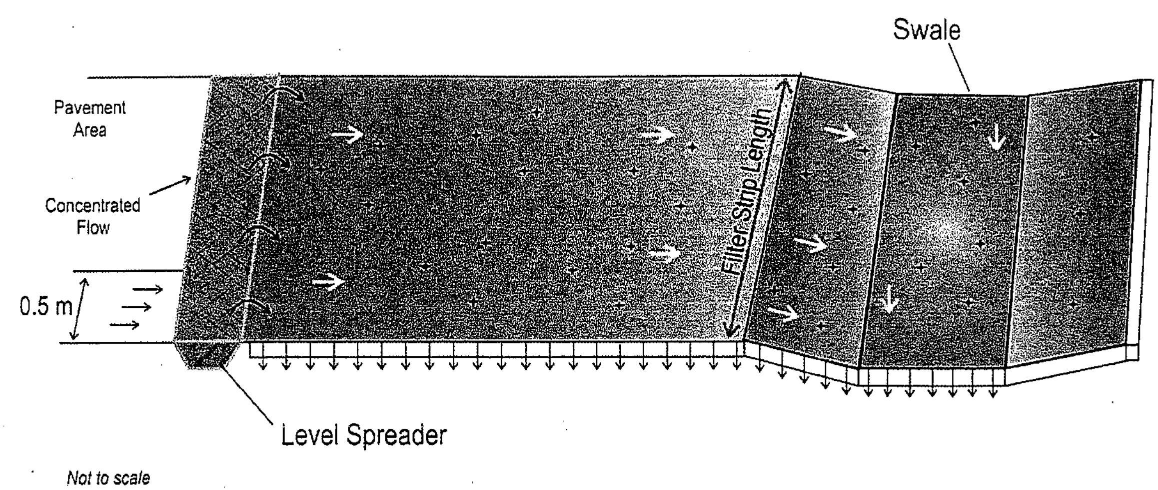
8-4.4 **Corrective Actions.** Dry wells can clog over time if there is extensive loading of fine grained sediment. Clogging is evident if there is standing water after a rain event at the surface of the facility. The appropriate corrective action is to first dig

[23] PGDER, 1993.
[24] LID Center, 2000.

out the gravel and then excavate to remove the sediment and uncover a layer of soils that has sufficient infiltration capacity.

8-5 **FILTER STRIPS** are bands of dense vegetation planted downstream of a runoff source.

Figure 8-4. Filter Strip



8-5.1 **Most Appropriate Uses.** The use of natural or engineered filter strips is limited to gently sloping areas where the vegetative cover is well-established and where channelized flow is not likely to develop. Filter strips are well suited for treating runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. They are also ideal components for the fringe of a stream buffer, or as pretreatment for a structural practice.

8-5.2 **Cost Data.** A rough estimate of filter strip construction costs includes the cost of seed or sod, approximately 30¢ per square foot for seed or 70¢ per square foot for sod. This amounts to a cost of between $32,000 and $74,000 per hectare ($13,000 and $30,000 per acre) for filter strips. The cost of filter strip construction may be higher than other stormwater management practices, but the construction costs are offset by low maintenance costs, roughly $865 per hectare ($350 per acre) per year.[25] Additionally, maintenance costs might overlap with regular landscape maintenance costs.

8-5.3 **Maintenance Issues.** Filter strips require standard vegetation management, such as mowing, irrigation, and weeding. Typical maintenance activities include inspection of filter strips at least twice annually for erosion or damage to vegetation and additional inspection after periods of heavy runoff. Recent research on biofiltration swales indicates that grass height and mowing frequency have little impact on pollutant

[25] Adapted from SWRPC, 1991.

removal rates.[26] Therefore, mowing may only be necessary once or twice a year for safety and aesthetics or to suppress weeds and woody vegetation.

8-5.4 **Corrective Actions.** Trash tends to accumulate in filter strip areas, particularly along highways. The need for litter removal should be determined through periodic inspection, but litter should always be removed prior to mowing.

8-6 **VEGETATED BUFFERS.** Vegetated buffers trap and filter sediments, nutrients, and chemicals from surface runoff and shallow groundwater.

Figure 8-5. Riparian Buffer Management.

Rural Cropland	**Zone 3** Grass	**Zone 2** Managed Forest	**Zone 1** Undisturbed Forest	**Streambed**	**Zone 1** Undisturbed Forest	**Zone 2** Managed Forest	**Zone 3** Grass	**Urban/Suburban** Developed
Farmers employ agricultural Best Management Practices	Grass helps to evenly spread surface waterflow and absorb nutrients	Trees can be harvested. Organic soils remove nitrogen	Tree roots help stabilize streambank	Woody debris slows velocity of water and improves aquatic habitat	Trees shade stream and keep water cool	Soil particles trap phosphorus, and trees use excess nutrients for growth	Porous grass-covered land increases infiltration and water storage. Controls concentrated runoff	People practice conservation measures

Source: Maryland Cooperative Extension Fact Sheet 724.

8-6.1 **Most Appropriate Uses.** Maintaining a vegetated buffer along creeks, streams, and rivers provides an attractive landscape and can improve water quality by removing sediment and chemicals before they reach the waterway. In addition, buffers provide flood control, help recharge groundwater, prevent soil erosion, and preserve or improve certain types of wildlife habitat. Well-designed buffers can also stabilize the stream bank and help absorb stormwater runoff.

8-6.2 **Cost Data.** Forest buffer costs range between $540 and $1800 per hectare ($218 and $729 per acre) to plant and maintain. Planting costs depend on geographic location, number of acres planted, number of trees planted per acre, species of trees, and whether or not the trees are from bare root or container stock. Grass buffers tend to cost less than forest buffers to plant and maintain ($415 to $ 1000 per hectare [$168 to $400 per acre]).

8-6.3 **Maintenance Issues.** Buffers should be monitored and managed to maintain their maximum water quality benefits and, where desired, wildlife habitat benefits. They should be inspected at least once a year, and always within a few days after severe storms, for evidence of sediment deposition, erosion, or development of concentrated flow channels. Weed and invasive species control is essential for the survival and rapid

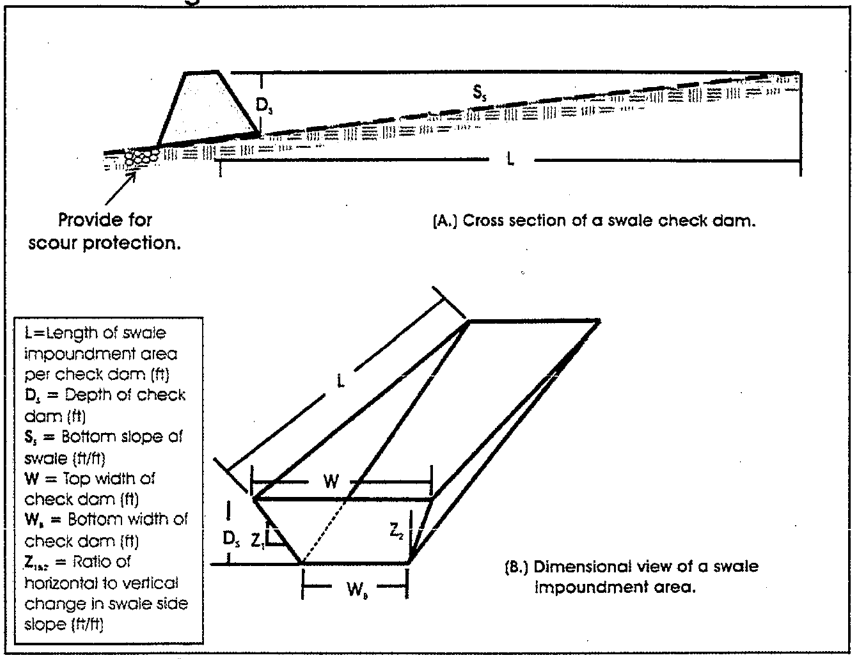
[26] Colwell et al., 2000.

growth of trees and shrubs. It is best to avoid working in the riparian area between April 15 and August 15, when a variety of animals are bearing their young.

8-6.4 **Corrective Actions.** If the buffer width is sufficient, vegetated buffers should be self-maintaining. Changes in hydrology, drought, over-grazing or natural disasters such as flooding or fire may require the replanting or reestablishment of the buffer.

8-7 **GRASSED SWALES** are shallow grass-covered hydraulic conveyances that help to slow runoff and facilitate infiltration.

Figure 8-6. Grassed Swale Schematic



Source: NVPDC, 1991. In EPA, 1999d.

8-7.1 **Most Appropriate Uses.** The suitability of grassed swales depends on land use, soil type, slope, imperviousness of the contributing watershed, and dimensions and slope of the grassed swale system.[27] In general, grassed swales can be used to manage runoff from drainage areas that are less than 4 ha (10 acres) in size, with slopes no greater than 5 percent. Use of natural low-lying areas is encouraged and natural drainage courses should be preserved and utilized.[28]

[27] Schueler et. al., 1992.
[28] Young et al., 1996

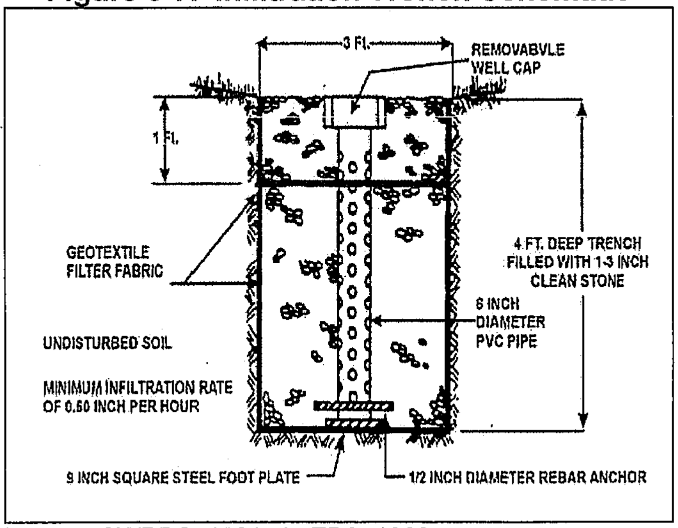
8-7.2 **Cost Data.** Grassed swale construction costs are estimated at approximately $2.70 per square meter ($0.25 per square foot.)[29] These costs, however, do not include design costs, raising the total cost to approximately $5.40 per square meter ($0.50 per square foot.) Grassed swale costs compare favorably with other stormwater management practices.[30]

8-7.3 **Maintenance Issues.** The maintenance objectives include keeping up the hydraulic and removal efficiency of the channel and maintaining a dense, healthy grass cover. Maintenance activities should include periodic mowing (with grass never cut shorter than the design flow depth), weed control, watering during drought conditions, reseeding of bare areas, and clearing of debris and blockages.

8-7.4 **Corrective Actions.** Cuttings should be removed from the channel. Accumulated sediment should also be removed manually to avoid concentrated flows in the swale. Avoid applying fertilizers and pesticides. The grass cover should be thick and reseeded as necessary. Any standing water removed during the maintenance operation must be properly disposed of at an approved discharge location.

8-8 **INFILTRATION TRENCHES.** Infiltration trenches are trenches that have been back-filled with stone. These trenches collect runoff during a storm event and release it into the soil by infiltration.

Figure 8-7. Infiltration Trench Schematic



Source: SWRPC, 1991. In EPA, 1999c.

8-8.1 **Most Appropriate Uses.** Infiltration trenches may be used in conjunction with another stormwater management device, such as a detention pond, to provide both water quality control and peak flow attenuation.[31] Runoff that contains high levels of sediments or hydrocarbons (oil and grease) that may clog the trench are often

[29] SEWRPC, 1991.
[30] Brown and Schueler, 1997.
[31] Harrington, 1989.

pretreated with other devices such as grit chambers, water quality inlets, sediment traps, swales, and vegetated filter strips.[32]

8-8.2 **Cost Data.** Construction costs include clearing, excavation, placement of the filter fabric and stone, installation of the monitoring well and, where desired, establishment of a vegetated buffer strip. The 1993 construction cost for a large infiltration trench (1.8 m (6 ft) deep, 1.2 m (4 ft) wide, and with a 68 m^3 (2,400 ft^3) volume) ranges from $8,000 to $19,000. A smaller trench (0.9 m (3 ft) deep, 1.2 m (4 ft) wide, and with a 34 m^3 (1,200 ft^3) volume) is estimated to cost from $3,000 to $8,500.

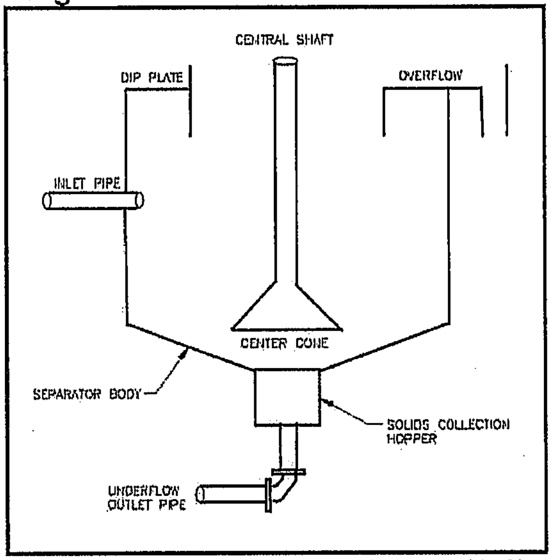
8-8.3 **Maintenance Issues.** The principal maintenance objective is to prevent clogging, which may lead to trench failure. Infiltration trenches should be inspected after large storm events and any accumulated debris or material should be removed. A thorough annual inspection should include monitoring of the observation well to confirm that the trench is draining properly. Trenches with filter fabric should be inspected for sediment deposits by removing a small section of the top layer and examining the material in the trench itself. When vegetated buffer strips are used, they should be mowed regularly and inspected for erosion or other damage after each major storm event.

8-8.4 **Corrective Actions**. The corrective action for infiltration trench failure is to remove the stone and sediment that has clogged the system. The trench should be over excavated and scarified to ensure that the infiltration capacity of the soil is sufficient. The stone is washed to remove any sediment and then replaced. It is critical that any surrounding areas be stabilized to eliminate the potential for sediment clogging.

8-9 **INLET DEVICES** (a.k.a. hydrodynamic separators). Inlet devices are flow-through structures with a settling or separation unit to remove sediments and other stormwater pollutants.

[32] SEWRPC, 1991; Harrington, 1989.

Figure 8-8. Inlet Device Schematic



Source: Tyack & Fenner, 1997. In EPA, 1999b.

8-9.1 **Most Appropriate Uses.** This technology may be used by itself or in conjunction with other stormwater management devices as part of an overall stormwater control strategy. Hydrodynamic separators are ideal for areas with limited land availability. In addition, hydrodynamic separators can be placed in almost any location in a system, making them ideal for use in potential stormwater "hotspots" (areas where higher concentrations of pollutants are more likely to occur; e.g. gas stations). Decreasing land availability for the installation of large stormwater management facilities is fueling the need for solutions such as hydrodynamic separators.

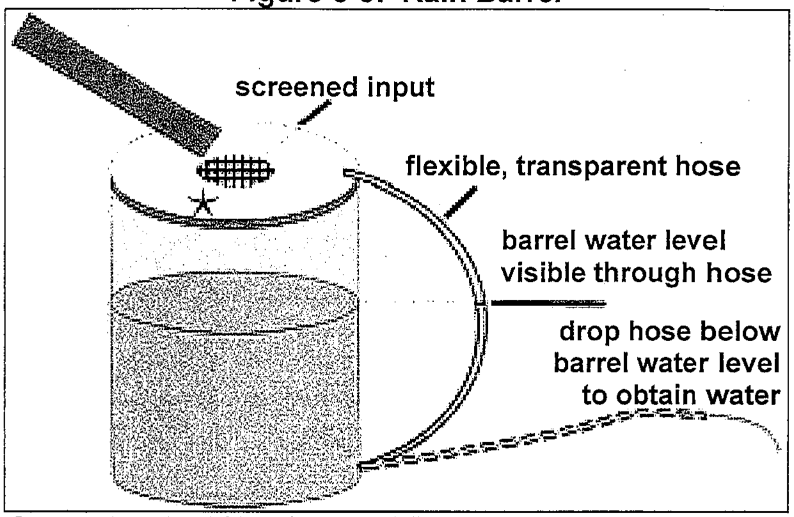
8-9.2 **Cost Data.** Costs are influenced by several factors including the amount of runoff to be treated, the amount of land available, and any other treatment technologies that are presently being used. Capital costs can range from $2,300 to $40,000 per pre-cast unit. Units that are site-specifically designed typically are more costly. Total costs for hydrodynamic separators often include pre-design costs, capital costs, and operation and maintenance costs.

8-9.3 **Maintenance Issues.** Proper maintenance of a hydrodynamic separator involves frequent inspections throughout the first year of installation to ensure that sediments are removed before the unit's sediment capacity is reached. Sediment depth can be measured using a "dip stick" or rod. Subsequently, sediment removal may be performed with a sump-vac or vacuum truck, depending on which type of separator is used. After the first year of installation, inspections can be scheduled according to observed rates of sediment accumulation. In general, hydrodynamic separators require a minimal amount of maintenance, but lack of attention will lower their overall pollutant removal efficiency.

8-9.4 **Corrective Actions.** Corrective action for structure or device failure typically requires removal and replacement of the device. Excessive bypass of sediments or pollutants may require additional devices or modification of the device.

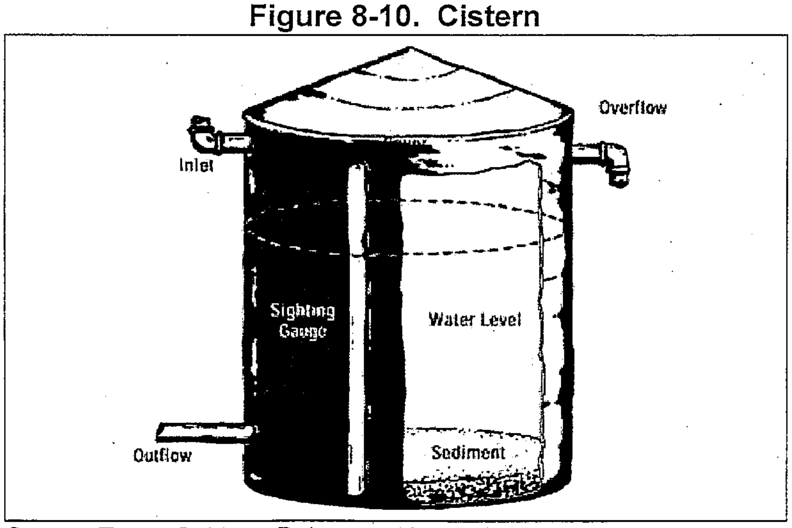
8-10 **RAIN BARRELS.** Rain barrels are placed outside of a building at roof downspouts to store rooftop runoff for later reuse in lawn and garden watering. **Cisterns** also collect rooftop runoff but store the water in significantly larger volumes in manufactured tanks or built underground storage areas. Both cisterns and rain barrels can be implemented without the use of pumping devices, instead relying on gravity flow.

Figure 8-9. Rain Barrel



Source: Maryland DNR Green Building Program.

Figure 8-10. Cistern



Source: Texas Guide to Rainwater Harvesting.

8-10.1 **Most Appropriate Uses.** Rain barrels and cisterns are low-cost water conservation devices that reduce runoff volume and, for very small storm events, delay and reduce the peak runoff flow rates. Both rain barrels and cisterns can provide a source of chemically untreated 'soft water' for gardens and compost, free of most sediment and dissolved salts.

8-10.2 **Cost Data.** The cost of a single rain barrel without any other attachments or accessories is typically around $120. The cost of constructing cisterns can vary greatly depending upon their size, material, location (above- or below-ground), and whether they are prefabricated. Pre-manufactured tanks utilized as cisterns can vary in price from hundreds to tens of thousands of dollars. Sizes can vary from hundreds of gallons for residential use to tens of thousands of gallons for commercial and industrial uses.

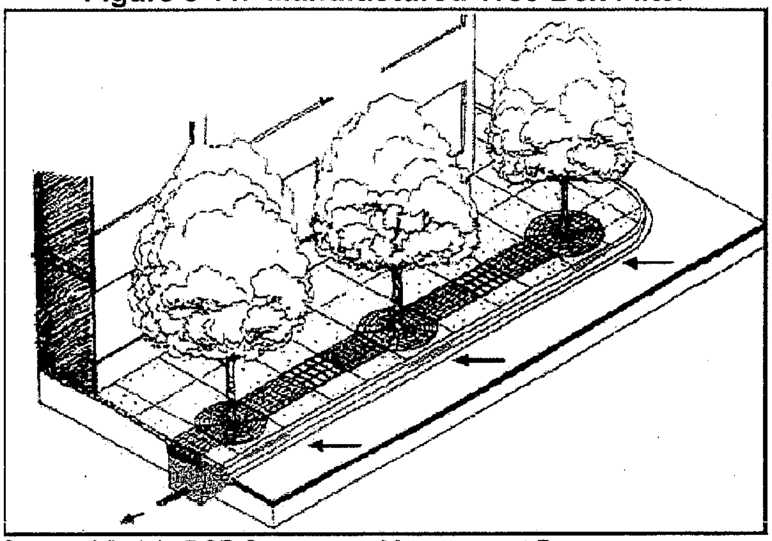
The use of water stored in rain barrels or cisterns for non-potable applications such as landscaping or toilets, or for potable applications if properly treated, may reduce potable water supply costs in areas where water costs are at a premium.

8-10.3 **Maintenance Issues.** Maintenance requirements for rain barrels are minimal and consist only of regular inspection of the unit as a whole and any of its constituent parts and accessories. All components should be inspected at least twice a year and repaired or replaced as needed. If cisterns are used to provide a supplemental supply of irrigation water, maintenance requirements for cisterns are often low. Cisterns designed for drinking water supply have much higher maintenance requirements, including biannual testing for water quality and filtering systems. Cisterns, along with all their components and accessories, should undergo regular inspection at least twice a year. Replacement or repair of the unit as a whole, and any of its constituent parts and accessories should be completed as necessary.

8-10.4 **Corrective Actions.** There are few mechanical parts on cisterns or rain barrels. Items such as screens or valves may fail, but are easily replaced. Large cisterns constructed out of materials such as metal or concrete may need repairs to walls by parging (for concrete) or welding (for metal).

8-11 **TREE BOX FILTERS.** Tree box filters are in-ground containers typically containing street trees in urban areas. These filters can be very effective at controlling runoff water quality, especially when numerous units are distributed throughout a site. Runoff is directed to the tree box, where it is filtered by vegetation and soil before entering a catch basin.

Figure 8-11. Manufactured Tree Box Filter



Source: Virginia DCR Stormwater Management Program.

8-11.1 **Most Appropriate Uses.** Tree box filters can help meet a variety of stormwater management goals, satisfy regulatory requirements for new development, protect and restore streams, control combined sewer overflows (CSOs), retrofit existing urban areas, and protect reservoir watersheds. The compact size of tree box filters allows volume and water quality control to be tailored to specific site characteristics. Tree box filters provide the added value of aesthetics while making efficient use of available land for stormwater management. Typical landscape plants (e.g., shrubs, ornamental grasses, trees and flowers) are an integral part of the bioretention system. Ideally, plants should be selected that can withstand alternating inundation and drought conditions, and that do not have invasive root systems which may reduce the soil's filtering capacity.

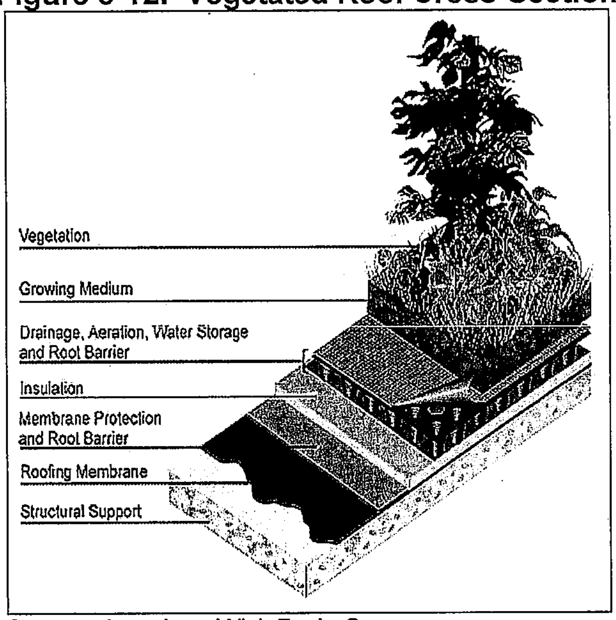
8-11.2 **Cost Data.** A single-unit tree box filter costs approximately $6,000 per unit per 0.1 ha (1/4 acre) of impervious surface (total cost = $24,000 per acre). This estimate includes two years of operating maintenance and filter material and plants. Additional costs include installation and annual maintenance. Installation varies with each site, but is approximately $1500 per unit. Annual maintenance is $500 per unit when performed by the manufacturer and $100 per unit when performed by the owner. (This sample cost estimate is based on a commercial tree box filter, the Filterra™ Stormwater Bioretention Filtration System.)

8-11.3 **Maintenance Issues.** Tree box filters require little maintenance. Maintenance includes annual routine inspection and the regular removal of trash and debris. The first two years of maintenance are typically included with the purchase of single and multiple-unit tree box filters. These would include removal of trash, debris and sediment, replenishment of the mulch, and care or replacement of plants. During extreme droughts, the plants may need to be watered in the same manner as any other landscape material.

8-11.4 **Corrective Actions.** Plants may have to be replaced because they have overgrown the filter, in which case their root structure may overwhelm the area of the soils, or because of environmental stress. The grates on top of the structure may become cracked and have to be replaced, although this should rarely occur because they are designed to be traffic bearing. The soil may become contaminated from a spill and have to be removed and properly disposed.

8-12 **VEGETATED ROOFS.** Vegetated roofs, also known as green roofs, eco-roofs or nature roofs, are structural components that help to mitigate the effects of urbanization on water quality by filtering, absorbing or detaining rainfall.

Figure 8-12. Vegetated Roof Cross-Section



Source: American Wick Drain Corp.

8-12.1 **Most Appropriate Uses.** Through a variety of physical, biological and chemical treatment processes that filter pollutants and reduce the volume of runoff, vegetated roofs reduce the amount of pollution delivered to the local drainage system and, ultimately, to receiving waters. One pollutant that vegetated roofs help control, for example, is nitrogen. While nitrogen gas occurs naturally as a major component of the atmosphere, nitrogen compounds from automobile exhaust, agricultural fertilizers and industrial activities can create a significant pollution problem. Airborne nitrogen compounds can fall to the ground in dust, raindrops, or simply by gravity. When these compounds are carried away with stormwater runoff, they contribute to eutrophication problems in surface water. Vegetated roofs can help control nitrogen pollution in stormwater runoff.

8-12.2 **Cost Data.** Costs for vegetated roofs in the United States are estimated to average between $161 and $215 per square meter ($15 and $20 per square foot) for all use types (i.e., high density residential, commercial, or industrial).[33] These costs include all aspects of vegetated roof installation, from the waterproofing membrane to soil substrate creation to planting. By far the highest costs associated with vegetated roof creation are the soil substrate and growth medium and the associated plant components. Vegetated roof retrofit projects may have increased cost associated with traffic and resource scheduling concerns as well as the on-site availability of equipment and materials. Planting costs are higher if plants are placed individually rather than pre-grown on vegetation mats.

8-12.3 **Maintenance Issues.** Once a properly installed vegetated roof is well established, its maintenance requirements are usually minimal. There are two basic types of vegetated roofing systems: extensive and intensive.

Extensive roofs form a thin vegetated sheath of self-sufficient mosses, sedums, and small shrubs. Their low profile allows them to be added to existing buildings, including those with sloping roofs.

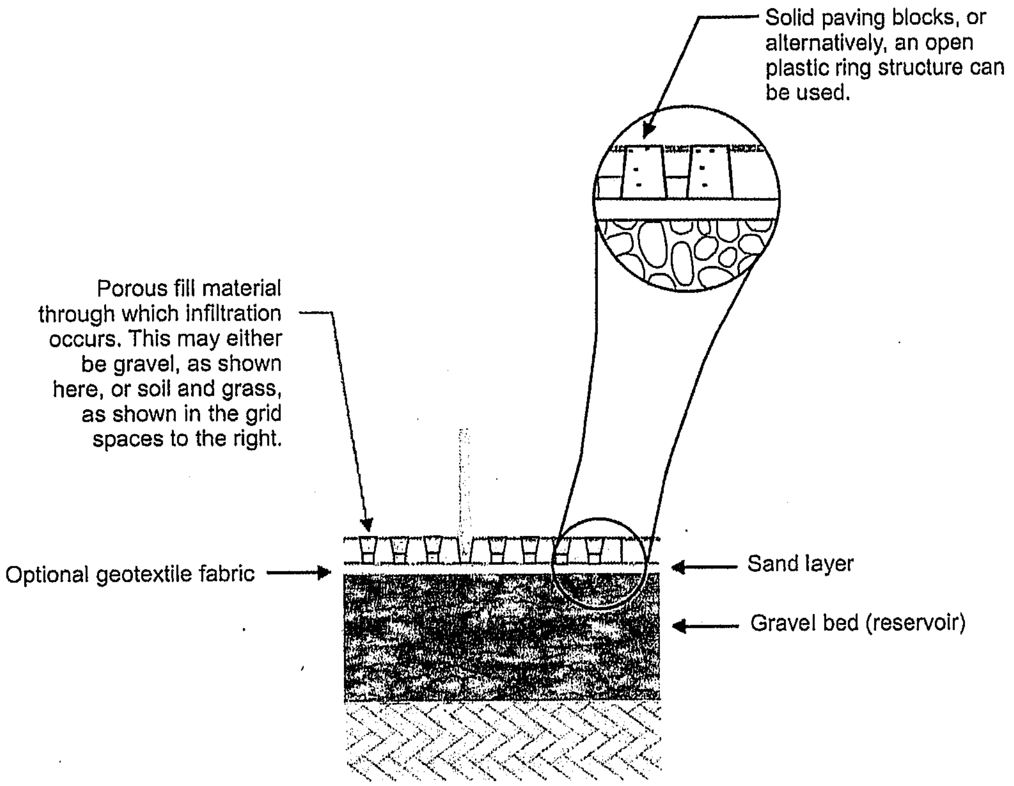
By contrast, intensive roofs are integral to the roof structure, permitting the use of trees and walkways. A greater depth of media may be required to accommodate larger vegetation and surface features. Intensive roofs require more structural as well as horticultural maintenance, similar to a conventional garden, because plantings tend to be both heavier and more elaborate than on extensive roofs. For both types of roofs, maintenance requirements typically include inspection of the roof membrane, the most crucial element of a vegetated roof, as well as inspection and preventive maintenance of the drainage layer flow paths.

8-12.4 **Corrective Actions.** Corrective actions for vegetated roofs are generally to repair localized problems. More complex systems may have monitoring devices incorporated into the membrane. Leak detection systems can be brought to the site to locate breaches in the membrane. The soil media can be removed and the membrane repaired. Long periods of drought or loss of soil to high winds may require replacement of the media or replanting. If drought becomes an issue, corrective actions include installing an irrigation system or scheduling supplemental watering.

8-13 **PERMEABLE PAVERS.** Permeable pavers allow water to seep through regularly interspersed void areas in order to reduce runoff and associated pollutants.

[33] Scholz-Barth, 2001.

Figure 8-13. Permeable Paver



Source: SCA Consulting Group, Lacey, WA.

8-13.1 **Most Appropriate Uses.** Runoff percolates through voids in permeable pavers and may be detained in the gravel bed, infiltrated into the underlying soil, or both. By reducing the volume of runoff, permeable pavers help to decrease downstream flooding, the frequency of combined sewer overflows, and the thermal pollution of sensitive waters. Permeable pavers can reduce or eliminate the requirement for underground sewer pipes and conventional stormwater retention and detention systems. Use of these materials can eliminate problems with standing water, provide for groundwater recharge, control erosion of streambeds and riverbanks, facilitate pollutant removal, and provide for a more aesthetically pleasing site. The drainage of paved areas and traffic surfaces by means of permeable systems is an important building block within an overall Low Impact Development scheme that seeks to achieve a stormwater management system that mimics natural conditions.

8-13.2 **Cost Data.** Initial expenses for alternative paving materials may be greater than conventional materials. However, the use of permeable pavers can often eliminate the requirement for underground storm drainpipes and conventional stormwater systems. Cost savings resulting from decreased investments in reservoirs, storm sewer extensions, and the repair and maintenance of storm drain systems should be considered. Interlocking concrete paving blocks cost $54 to $108 per square meter

($5.00 to $10.00 per square foot.) In general, the multifunctional nature of permeable pavers reduces overall costs.

8-13.3 **Maintenance Issues.** After installation of a permeable paver system, maintenance is minimal but absolutely necessary to ensure the long lifetime of the system. Grass pavers will require the normal watering and mowing maintenance of any turf system. Porous concrete and interlocking concrete paving blocks require that the surface be kept clean of organic materials (leaves, for example). Periodic vacuuming and low-pressure washing should be used to clear out voids and extend the paver's functional life. Conventional street sweepers should be used with vacuums, brushes and water ideally four (4) times a year, but the actual required frequency will be determined by local conditions. With the interlocking system, additional aggregate fill material may be required after cleaning.

8-13.4 **Corrective Actions.** If there is an extensive buildup of a "scum" layer within the voids, the chip stone should be vacuumed, power-washed, cleaned and replaced. In case of localized settling, individual paver blocks can be removed, new gravel added, and the blocks replaced. In case of spills or contamination, the blocks and gravel layers can be removed and the area remediated.

8-14 **PERMEABLE PAVEMENT** can be either asphalt or concrete. As with permeable pavers, water is allowed to pass through voids and infiltrate into the underlying soil. Permeable pavement lacks most of the fine material found in conventional pavements, allowing water to flow through voids in the aggregate. (By contrast, paver blocks themselves are not necessarily permeable; infiltration occurs in the gaps between the blocks.) A layer of clean, uniformly graded gravel lies beneath the pavement, and geotextile separates this stone bed from the soil below. Runoff from the paved surface and adjacent impervious areas slowly passes through the gravel layer, which also may serve as a storage area. Permeable pavement has the same structural properties as conventional pavement. Environmental benefits are similar to other IMPs: reduction of runoff volume and rate, pollutant filtering, flow dispersion, and groundwater recharge. In addition, permeable pavements reduce the footprint of a site's impervious area.

8-14.1 **Most Appropriate Uses.** Permeable pavement may be substituted for conventional pavement in any application; however, it is most commonly and successfully used in parking lots and walkways. Permeable pavements simultaneously serve as hardscape and as stormwater infrastructure, and are therefore especially practicable where space constraints preclude the use of other IMPs such as bioretention. Cahill Associates reports that large permeable paved areas are still functioning after 20 years, outlasting conventional pavements in some cases. Permeable pavements reduce the likelihood of sinkhole formation because runoff is dispersed over a large area (i.e., the entire paved surface), rather than concentrated in a small area such as a pond or catch basin.[34]

[34] Cahill Associates, 2003.

8-14.2 **Cost Data.** Permeable asphalt costs range from $5 t0 $11 per square meter ($0.50 to $1.00 per square foot,) while permeable concrete costs between $22 and $70 per square meter ($2.00 and $6.50 per square foot.) In addition, permeable pavements may reduce or eliminate the need for additional stormwater infrastructure, so a more accurate price comparison would involve the costs of the full stormwater management paving system. For example, a grass/gravel paver and porous concrete representative stated that when impervious paving costs for drains, reinforced concrete pipes, catch basins, outfalls and storm drain connections are included, an asphalt or conventional concrete stormwater management paving system costs between $102 and $125 per square meter ($9.50 and $11.50 per square foot,) compared to a permeable pavement stormwater management system at $50 to $70 per square meter ($4.50 to $6.50 per square foot.) The savings are considered to be even greater when permeable paving systems are calculated for their stormwater storage; if designed properly, they can eliminate retention pond requirements.[35]

8-14.3 **Maintenance Issues.** Maintenance requirements are similar to those for permeable pavers. To maintain its permeability, the pavement must be vacuumed or cleaned with a street sweeper twice a year. This removes sediments, organic matter, and atmospheric deposition that would otherwise clog the pavement over time.

8-14.4 **Corrective Actions.** With proper preventative maintenance, no additional actions should be necessary to maintain permeability. Pavements that have clogged as a result of neglect may require intensive vacuuming. As with conventional pavement, normal wear and tear may require repairs. For asphalt, however, care should be taken to *replace* the affected areas, because re-sealing would create an impervious surface. Contractors and maintenance staff should be acquainted with the differences between conventional and permeable pavement in order to prevent such a scenario.

Figure 8-14. Permeable Pavement Cross-Section

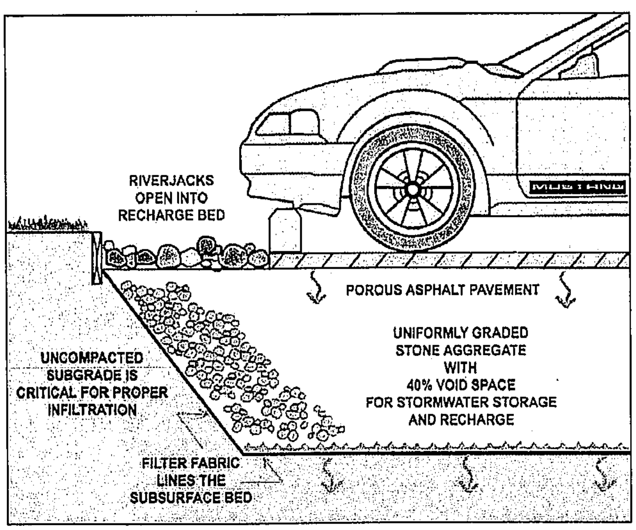
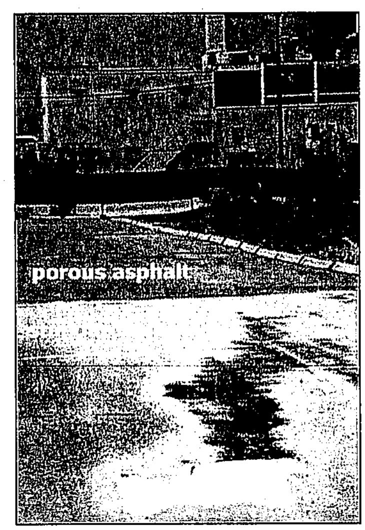


Figure 8-15. Drainage in Both Types of Pavement



[35] Peterson, 2002.

A008454

Source: Cahill Associates.

Source: Cahill Associates.

8-15 **TECHNICAL CONSULTATION.** With the possible exception of dry wells, infiltration trenches, and inlet devices, the vegetated IMPs described here are integral to a site's landscape design. Accordingly, they should be designed by, or under the direct supervision of, an appropriate licensed professional such as a landscape architect.

8-16 **DEVELOPMENT AND EVALUATION OF ADDITIONAL PRACTICES.** Additional practices not discussed in this UFC may also be appropriate for use as IMPs. The practice's applicability, effectiveness, cost and maintenance requirements must be considered in order to evaluate its potential use as an IMP.

CHAPTER 9

LID SITE PLANNING PROCESS

9-1 **INTRODUCTION.** This is a representative process for planning LID retrofits. Individual facilities will have unique needs and should adapt this process accordingly.

9-2 MODEL PLANNING PROCESS.

Step 1: Define project objectives and goals

1. Identify the LID objectives for the project. Consider these four fundamental aspects of stormwater control:[36]

    - Runoff volume
    - Peak runoff rate
    - Flow frequency and duration
    - Water quality

2. Evaluate existing stormwater infrastructure in terms of how well it functions with respect to each of these aspects.

3. Determine the goals and feasibility for control of runoff volume, flow frequency and duration, and water quality; as well as on-site use of stormwater (e.g. irrigation).

4. Prioritize and rank basic objectives.

5. Define hydrologic controls required to meet objectives (i.e. infiltration, filtration, discharge frequency, volume of discharges, groundwater recharge).

Step 2: Perform site evaluation and analysis

A site evaluation will facilitate LID design development by providing site details that will assist in the development of an LID program.

1. Conduct a detailed investigation of the site using available documents such as drainage maps, utilities information, soils maps, land use plans, and aerial photographs.

2. Perform an on-site evaluation highlighting opportunities, such as pollutant-generating areas, potential disconnects from combined sewer systems, and potential green corridors. Note potential LID practices and areas where water quality and quantity controls could be installed.

[36] PGDER, 2000b.

3. Evaluate site constraints such as available space, soil infiltration characteristics, water table, slope, drainage patterns, sunlight and shade, wind, critical habitat, circulation and underground utilities.

4. Identify protected areas, setbacks, easements, topographic features, subdrainage divides, and other site features that should be protected such as floodplains, steep slopes, and wetlands.

5. Delineate the watershed and microwatershed areas. Take into account previously modified drainage patterns, roads, and stormwater conveyance systems.

6. Locate baseline hydrologic and water quality data. In order of preference, try to locate:

   a) Local stream gage data and site water quality sampling data
   b) Data from a similar area within region
   c) Local averages
   d) Modeling results

7. Identify applicable local regulations or codes.

Step 3: Develop LID control strategies

Use hydrology as a design element. In order to minimize the runoff potential of the development, the hydrologic evaluation should be an ongoing part of the design process. An understanding of site drainage can suggest locations both for green areas and potential building sites. An open drainage system can help integrate the site with its natural features, creating a more aesthetically pleasing landscape.

1. Determine the design storm(s). Regulatory requirements for design storms may also be stipulated in local ordinances, and these may limit or constrain the use of LID techniques or necessitate that structural controls be employed in conjunction with LID techniques.

2. Define modeling technique(s) to be employed. Section 5-5.1 includes a detailed description several available hydrologic models. The model selected will depend on the type of watershed, complexity of the site planning goals, familiarity with the model, and level of detail desired.

3. Evaluate current conditions. Use the results of modeling to estimate baseline values for the four evaluation measures: runoff volume, peak runoff rate, flow frequency and duration, and water quality.

4. Implement non-structural site planning techniques:

   a) Minimize total site impervious area.

- Use alternative roadway layouts that minimize imperviousness.
- Reduce road widths.
- Limit sidewalks to one side of roads.
- Reduce on-street parking.
- Use permeable paving materials.

b) Minimize directly connected impervious areas.

- Disconnect roof drains. Direct flows to vegetated areas.
- Direct flows from paved areas to stabilized vegetated areas.
- Break up flow directions from large paved surfaces.
- Encourage sheet flow through vegetated areas.
- Locate impervious areas so that they drain to permeable areas.

c) Modify drainage flow paths to increase time of concentration (T_c).

- Maximize overland sheet flow.
- Lengthen flow paths and increase the number of flow paths.
- Maximize use of open swale systems.
- Increase (or augment) the amount of vegetation on the site.

d) Define the development envelope.

- Use site fingerprinting. Restrict ground disturbance to the smallest possible area.
- Reduce paving.
- Reduce compaction of highly permeable soils.
- Minimize size of construction easements and material stockpiles.
- Place stockpiles within development envelope during construction.
- Avoid removal of existing trees.
- Disconnect as much impervious area as possible.
- Maintain existing topography and associated drainage divides to encourage dispersed flow paths.
- Locate new development in areas that have lower hydrologic function, such as barren clayey soils.

5. Evaluate site planning benefits and compare with baseline values. The modeling analysis is used to evaluate the cumulative hydrologic benefit of the site planning process in terms of the four evaluation measures.

6. Evaluate the need for Integrated Management Practices (IMPs). If site planning is not sufficient to meet the site's LID objectives, additional hydrologic control needs may be addressed through the use of IMPs (described in Chapter 8). After IMPs are selected for the site, a second-level hydrologic evaluation can be conducted that combines the IMPs with the controls provided by the planning techniques. Results of this hydrologic evaluation are compared with the baseline conditions to verify

that the site LID objectives have been achieved. If not, additional IMPs are located on the site to achieve the optimal condition.

7. Evaluate supplemental needs. If supplemental control for either volume or peak flow is still needed after the use of IMPs, selection and listing of additional management techniques should be considered. For example, where flood control or flooding problems are key design objectives, or where site conditions, such as poor soils or a high water table, limit the use of IMPs, additional conventional end-of-pipe methods, such as large detention ponds or constructed wetlands, should be considered. In some cases their capacity can be reduced significantly by the use of LID upstream. It may be helpful to evaluate several combinations of LID features and conventional stormwater facilities to determine which combination best meets the stated objectives. Use of hydrologic evaluations can assist in identifying the alternative solutions prior to detailed design and construction costs.

For residential areas, Prince George's County, Maryland, has developed a detailed illustration of an approach for conducting a hydrologic evaluation based on the NRCS TR-55 method. Where NRCS methods (TR-20, TR-55) are accepted for hydrologic evaluation, the effect of LID features should be reflected in the curve numbers and times of concentration selected for the analysis. A full description of this process is available from Prince George's County.[37]

Step 4: Design LID Site or Master Plan

1. Sketch a design concept that distributes the LID practices appropriately around the project site. Try to use all surface types (built, hardscape, and landscape). Keep in mind the multifunctional capability of LID technologies (i.e., parking lot with detention facility underground).

2. Develop a master plan that identifies all key control issues (water quality, water quantity, water conservation) and implementation areas. Specify specific LID technologies and any connections they have to stormwater overflow units and sub-surface detention facilities.

Step 5: Develop Operation and Maintenance Procedures

Develop operation and maintenance procedures for each of the LID practices implemented in the site plan. Different types of IMPs will have different maintenance requirements, but some general principles will apply:

- Keep IMPs and flow paths clear of debris.
- Water vegetation regularly during dry periods.
- Grassed areas should be mowed regularly.
- Plantings should be pruned as needed.

[37] PGDER, 2000b.

Specific maintenance requirements of the different IMPs are discussed in Chapter 8.

CHAPTER 10

DESIGN EXAMPLES

10-1 **OFFICE COMPLEX RETROFIT.** This example illustrates how an existing office building complex can be retrofit with LID components to improve water quality. This complex is located at the Anacostia Annex of the Washington Navy Yard in Washington, D.C. This area has extremely flat topography with clay soils. Because of its proximity to the Anacostia River, there is a high water table. No stormwater management quantity or quality controls are currently being used. The existing asphalt surface has been patched several times and is in poor condition. A full-depth replacement of the parking area is required. Many of the drainage inlets and old brick drainage structures are cracked or broken and need to be replaced. Much of the sidewalk surrounding the building is also cracked or heaving and the site pedestrian access does not comply with current Americans with Disabilities Act (ADA) Standards. Much of the existing vegetation around the building is overgrown and the lawn areas are in poor condition from compaction and poor management. This condition creates an opportunity to retrofit the parking area for immediate water quality improvements and make long-term recommendations for the entire area.

Figure 10-1. Landscaped Area and Parking Area

10-1.1 **PROJECT OBJECTIVES.** The objectives for this retrofit are to:

- Integrate water quality management practices into the repaving of parking areas
- Repair the sidewalks
- Re-landscape

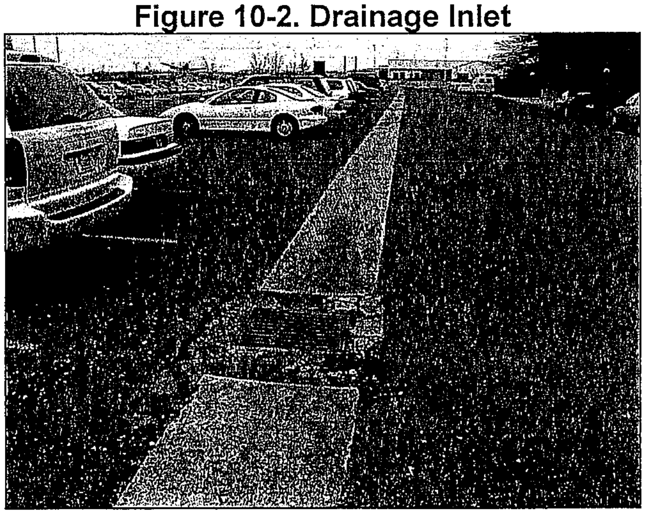
Funding for LID retrofits has been approved as part of the paving and reconstruction so that the area will comply with local stormwater quality regulations. Pollutants of concern for this watershed are oils and grease, total suspended solids, nitrogen, and phosphorus. All of these pollutants are generated by the land use. In this case, as with many retrofits, the goal is to improve stormwater quality generally rather than to meet a specific load reduction goal. Quantity control is not required because the site outfall is located near the outlet of the watershed of a major watercourse and the facility's storm drain network has adequate capacity.

10-1.2 **RANK AND PRIORITIZE OPPORTUNITES.** For this project, retrofit opportunities will be ranked and prioritized according to the following criteria:

- Greatest potential to reduce non-point source pollutant loads
- Minimal costs for new structures or materials
- Minimal disturbance and ability to integrate construction into storm drain repair
- Minimal maintenance cycles
- Minimal maintenance costs and training
- Ancillary benefits (landscaping, energy conservation, water conservation)

10-1.3 **SITE CONDITIONS.** The site has minimal topographic relief. The groundwater table is approximately 3 feet (0.91 m) below the surface elevation. The soils in the area are fill soils with poor infiltration rates. The site is fronted by a landscaped buffer along the access road. There is an existing drainage system below the buffer. The adjacent parking area has several mature trees and drains towards the landscape buffer area. Figure 10-1 is a picture of the landscaped area taken from the parking area. Several yard inlets are located in the parking areas and along the access road. Figure 10-2 is a picture of a drainage inlet that has a concrete pilot channel to help collect runoff from the parking areas.

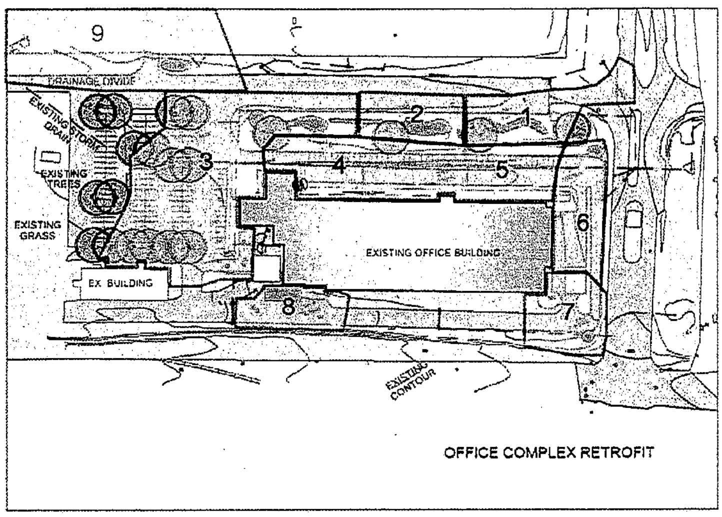
Figure 10-2. Drainage Inlet



Utility maps, topographic maps, and aerial photography were gathered and a site visit was conducted. Drainage patterns were verified during the site visit. (Drainage areas and patterns found in the field often deviate from those shown on plans because of changing field conditions, new utilities, repairs, or inaccuracies in the data.)

10-1.4 **LID DESIGN.** Four types of LID components were selected: bioretention, permeable pavers, tree box filters, and a vegetated roof. Because of the poor infiltration capacity of the soil, these features will not be capable of infiltrating stormwater into the ground. Instead, they will be equipped with underdrains and used to control water quality and provide detention storage. Site drainage areas were delineated, and LID features were located in places both appropriate to the technology and to the runoff patterns and volumes. Figure 10-3 shows the site drainage patterns and Figure 10-4 shows the locations of the LID features.

Figure 10-3 Drainage Areas of Proposed Practices



The description of the practices and their locations is as follows:

- **Drainage Areas One through Three:** Several LID components will be installed in the large vegetated island behind the parking areas along the access road. The design includes three bioretention cells, a bioretention swale, and a footpath constructed using permeable pavers. Installation will require that the existing curb be removed and replaced with wheel stops. These LID components can then treat the sheet flow from the access road and adjacent parking area and the parking lot to the south. A slight regrading of the drive area around the access road to the building will be required in order to direct runoff from the parking lot to the bioretention cells.

- **Drainage Area Four:** A tree box filter is designated for this area. This structure is appropriate because of space limitations.

- **Drainage Area Five:** Permeable pavers will be constructed in the existing valley between the access road and the parking area. This will require reconstruction of the inlet tops and some regrading. The curb in the back of the parking area is also deteriorated and should be replaced. The width of the pavers will be based on their infiltration capacity. The depth to groundwater also needs to be determined to make sure that the gravel bed underneath the pavers can be properly constructed to store and drain stormwater.

- **Drainage Area Six:** A bioretention cell will be constructed within a vegetated island at the north end of this parking area.

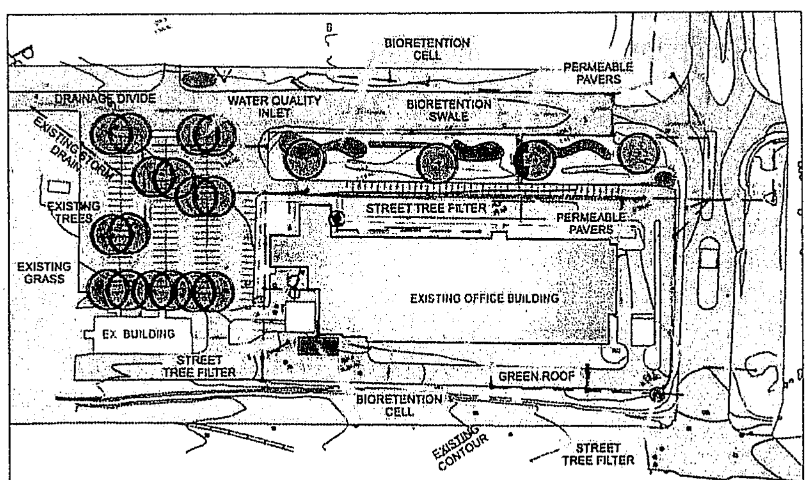
- **Drainage Area Seven:** An area of the pavement will be removed and replaced with a bioretention cell.

- **Drainage Area Eight:** This is near the loading dock area. Permeable pavers will be constructed. A sand layer may be incorporated into the system to increase efficiency.

- **Drainage Area Nine:** A bioretention cell will be located to the east of the access road, near the entrance to the storage lot to the south of building 399. This area will treat runoff from the access road and the storage area. The driveway apron will be reconstructed to direct runoff to the cell.

- **Rooftop:** A vegetated roof is proposed for building 168. This will filter pollutants from rain falling on the rooftop and will provide detention of rooftop runoff.

Figure 10-4. Office Complex Retrofit



OFFICE COMPLEX RETROFIT

Pollutant load calculations were developed for this project using a spreadsheet and a modification of the Simple Method[38] to determine the optimal areas in which to locate water quality improvement features. Although this method is more appropriate for larger watersheds and preliminary planning, the local jurisdiction uses it to evaluate water quality loading. Equation 10-1 is the water quality calculation.

Equation 10-1

$$L = 0.226 \times R \times C \times A$$

Where: L = Annual load (lbs)
R = Annual runoff (inches)
C = Pollutant concentration (mg/l)
A = Area (acres)
0.226 = Unit conversion factor
(Schueler, 1987)

Equation 10-2 is the projected load reduction.

Equation 10-2

$$D = L \times (1 - E)$$

Where: D = Annual load reduction (lbs)
L = Annual load (lbs)
E = Pollutant removal efficiency (fraction)

For the purposes of this study, removal rates of 70 percent were used for bioretention and tree box filters, and a removal rate of 50 percent was used for permeable pavers. Calculations were performed for lead, copper, zinc, phosphorus and total nitrogen. The results show an overall reduction of almost 65 percent of the aggregate load for the areas directly controlled by the practices and 55 percent of the total annual load for the pollutants studied. Table 10-1 shows the projected load reduction for various pollutants.

Table 10-1. Projected Load Reduction After LID Retrofit

Pollutant	Annual Load kg (lbs) Existing Condition	Annual Load (lbs) After LID Retrofit
Zinc	7.94 (17.5)	2.8 (6.1)
Lead	7.76 (17.1)	2.7 (6.0)
Copper	2.1 (4.6)	0.73 (1.6)
Nitrogen (TKN)	43.4 (95.6)	15.1 (33.2)
Phosphorus	20.2 (44.5)	7.03 (15.5)

10-2 **NEW HOUSING DESIGN.** This example will demonstrate the differences between conventional and LID stormwater management approaches for a typical DoD housing community in a coastal area. The design objectives are to maintain the peak runoff rate for a Type II NRCS 2-year 24-hour storm event and provide water quality control for the development. Following the hydrologic analysis presented here, a series

[38] Schueler, 1987.

of pictures are presented to illustrate how selected LID components would look in a recently constructed housing development.

10-2.1 **Curve Number Calculations For Existing Site Condition.** The site being evaluated has a 2.6 ha (6.5 acre) drainage area. The land is relatively flat and drains to a small channel with wetlands at the outfall of the drainage area. The slopes are gentle, averaging 2 percent. The soils are classified as belonging to NRCS Hydrologic Soils Group (HSG) B. These soils have moderate infiltration rates and moderately fine to moderately coarse textures. They generally have a moderate rate of water transmission (0.15 to 0.30 in/hr), and the textures may be classified as a silt loam or loam.[39] Approximately 1.5 ha (3.6 acres) near the outfall is classified hydrologically as "Woods in Fair Condition". The upper portion of the property is classified as "Brush in Poor Condition". Figure 10-5 is a map of the existing condition.

The procedures from Worksheet 2, Figure 2-5 from TR-55[40] are used to calculate the composite curve number (CN) for the site. The resulting CN from Equation 10-3 is 63 for the 2.6 ha (6.5 acres.) Table 10-2 is a summary of those calculations.

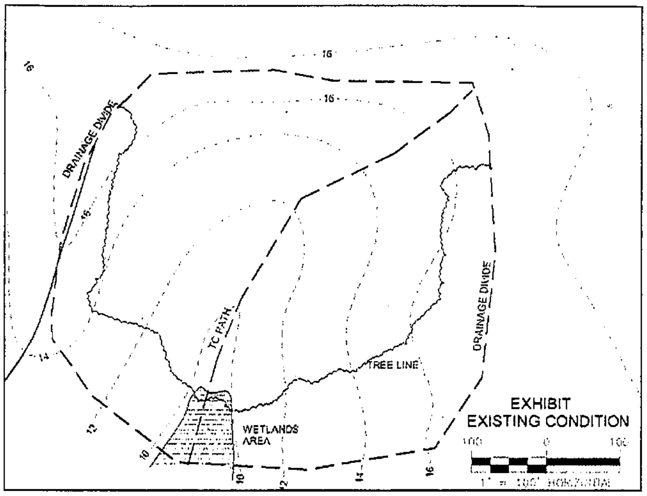
Weighted CN = Sum of Products ÷ Drainage Area **Equation 10-3**

Table 10-2. Composite Curve Number Calculation for Existing Condition

Hydrologic Soils Group	Cover Description	CN (Table 2-2 TR-55)	Area (Acres)	Product of CN x Area
B	Brush, Poor Condition	67	2.9	194.3
B	Woods, Fair	60	3.6	216.0
			Sum of Products	**410.3**
			÷ Drainage Area	6.5
			Weighted CN	**63**

[39] NRCS, 1986.
[40] Ibid.

Figure 10-5. Map of Existing Conditions



10-2.2 **Post Development Curve Number Calculations.** The conventional method for assigning a curve number to a residential development is to choose a single curve number for the entire site from a source such as Table 2-2a of TR-55.[41] Figure 10-6 is a picture of the proposed housing type, which can be classified as "Townhouse Residential District". For this land use, the CN from Table 2-2a of TR-55 is 85.

The LID method allows for the calculation of a "customized" CN that reflects the actual field conditions rather than a broad estimation. For this example, the amounts of impervious cover and other land covers were calculated directly from Figure 10-7. Table 10-3 is a summary of the proposed condition's "customized" CN using the LID calculation method.

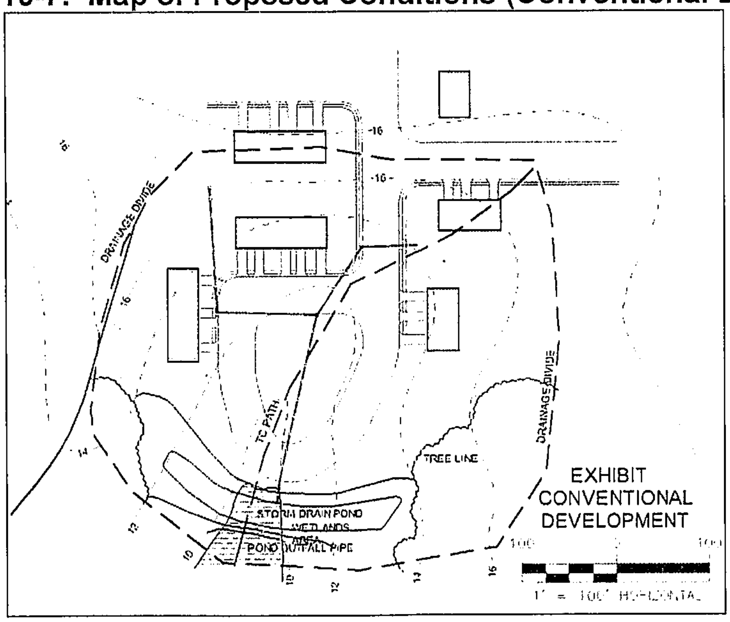
Table 10-3. Composite Curve Number Calculation for Proposed Condition

Hydrologic Soils Group	Cover Description	CN (Table 2-2 TR-55)	Area (Acres)	Product of CN x Area
B	Lawn (fair condition)	69	3.2	220.8
B	Woods, Fair	60	0.7	42.0
B	Impervious	98	2.6	254.8
			Sum of Products	**517.6**
			÷ Drainage Area	6.5
			Weighted CN	**80**

[41] Ibid.

Figure 10-6. Proposed Housing

Figure 10-7. Map of Proposed Conditions (Conventional Design)



10-2.3 **Runoff Volume For Existing And Proposed Conditions.** The difference in runoff volume between the existing and proposed conditions can be quite significant for both annual accumulations and peak events. A comparison of the volume (depth) of runoff from the pre- and post-development curve numbers for a 130 mm (5-in) rainfall using Equation 2-1 from TR-55[42] (Equation 10-4) is shown in Table 10-4.

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$ **Equation 10-4**

Where: Q = runoff depth (in)
P = rainfall depth (in)
I_a = initial abstraction (in)

$$I_a = 0.2S$$ **Equation 10-5**

Where: S = potential maximum retention after runoff begins (in)

$$S = \frac{1000}{CN} - 10$$ **Equation 10-6**

Table 10-4. Runoff Depth for Existing and Proposed Conditions (5-inch Rainfall)

Condition	Runoff (in)
Existing (CN = 63)	1.5
Proposed (CN = 80)	2.9

10-2.4 **LID Site Planning Strategies.** Several LID site design strategies will be employed to reduce the CN for the proposed condition. A lower CN value will be obtained by:

- Reducing impervious cover
- Disconnecting impervious areas
- Reducing the grading footprint to retain more wooded area
- Restoring the infiltration capacity of disturbed and compacted soils

Figure 10-8 shows the resulting site plan. A significant amount of disturbance to the woods and wetlands has been avoided by eliminating the centralized stormwater facility and distributing the stormwater management among LID components throughout the site. (The elimination or reduction of impacts to wetlands and water bodies may have a significant effect on permitting in many areas.) The condition of lawn areas will be improved by ensuring that adequate topsoil and aeration are included in the final grading and stabilization of the project. The road width has been reduced from 15 m (48 ft) to 9.8 m (32 ft). The parking areas have been maintained as head-in parking and the green space in the central island is expanded. Additional reductions in impervious area could be incorporated into the design, such as further reducing the road width or sharing driveways. Remaining impervious areas should be disconnected to the greatest possible extent. Table 10-5 summarizes the CN calculations for the proposed conditions using the LID site planning approach.

[42] Ibid.

Figure 10-8. Map of Proposed Conditions (LID Design)

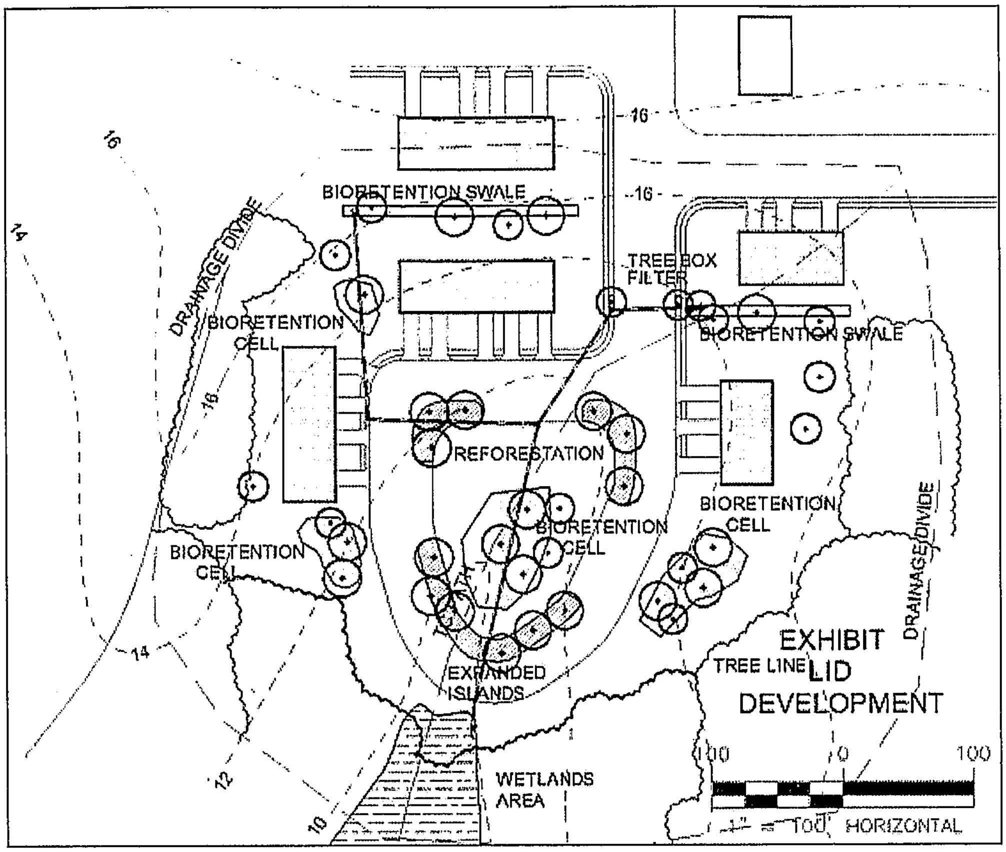


Table 10-5. Composite CN Calculation for Proposed Condition Using LID

Hydrologic Soils Group	Cover Description	CN (Table 2-2 TR-55)	Area (Acres)	Product of CN x Area
B	Lawn (good condition)	61	1.8	109.8
B	Woods, Fair	60	2.5	150.0
B	Impervious	98	2.2	215.6
			Sum of Products	**475.4**
			÷ Drainage Area	6.5
			Composite CN	**73**

10-2.5 **Time Of Concentration For Existing And Proposed Conditions.** The time of concentration (T_c) was calculated for the pre-development and conventional post-development conditions using the procedures in TR-55. A summary of these calculations is included in Appendix C. The conventionally developed condition causes T_c to decrease from 0.24 hours to 0.22 hours, or a 1.2 minute difference. The LID site design results in a T_c that matches the existing condition; in this case, 0.24 hours. Additional calculations for flow through the bioretention cells or rougher vegetated areas were not included in the analysis, but would be expected to further increase post-development LID T_c.

10-2.6 **Storage Volume Comparison.** A comparison of the storage volumes required for the conventional and LID site designs is given below. The 2-year 24-hour and the 10-year 24-hour storms are often used as the design storms for channel protection and adequate conveyance. Although the design objective here is to maintain the peak runoff rate for the 2-year 24-hour storm, the 10-year 24-hour storm is also used to further illustrate the differences in peak runoff rate and volume between the two approaches. In order to determine the storage volume required to maintain the pre-development peak runoff rate for these design storms, the runoff depths and peak runoff rates for the existing condition and both proposed conditions were first calculated using the Graphical Peak Discharge Method from TR-55. Table 10-6 is a summary of those calculations.

Table 10-6. Summary of Graphical Peak Discharge Results

Condition	CN	T_c	Peak Discharge (CFS)		Runoff depth (in.)	
			2-year storm (3" depth)	10-year storm (5" depth)	2-year storm	10-year storm
Existing Condition	63	0.24	2	10	0.4	1.5
Proposed Condition – conventional CN	80	0.22	9	23	1.3	2.9
Proposed Condition using LID site design	73	0.24	6	17	0.9	2.3

The TR-55[43] computer program was used to estimate the post-development storage volume required to maintain the 2-year 24-hour pre-development peak runoff rate for both the conventional and LID site designs. As shown in Table 10-6 above, the target (existing) 2-year 24-hour peak outflow is 2 cfs and the target 10-year 24-hour peak outflow is 10 cfs. (It is purely coincidental that the values of the return periods match the values of the discharges.) The results are given in Table 10-7.

Table 10-7. Post-Development Storage Volumes

Design storm	Conventional site design		LID site design	
	Depth, inches (mm)*	Volume, ac-ft (m^3)	Depth, inches (mm)*	Volume, ac-ft (m^3)
2-year 24-hour	0.52 (13)	0.28 (347)	0.28 (7)	0.15 (187)
10-year 24-hour	0.85 (22)	0.46 (568)	0.53 (13)	0.29 (354)

** depth of runoff distributed across the 6.5 acre (2.6 ha) area*

For the 2-year 24-hour storm, the LID site design results in a 46% reduction in required storage volume as compared to the conventional site design, and for the 10-year 24-hour storm, the volume reduction is 38%. The pond shown in Figure 10-7 was sized using the computed 2-year conventional detention basin storage volume. Appendix C shows a summary of the computer program results.

[43] Ibid.

10-2.7 **Distributed Detention And Retention Storage Requirements.** The previous section demonstrates that significant reductions in runoff volume (and correspondingly, storage volume) can be achieved by following the LID site design approach. A conventional detention pond, however, will not normally be used in an LID design; instead, storage will be provided using *distributed* retention and detention. The LID Design Charts (see Appendix D)[44] were used to determine the total volume of storage required to maintain the pre-development 2-year 24-hour peak runoff rate using retention (Chart 1) and detention (Chart 2). The CN of 63 was used for the pre-development condition and the CN of 73 was used for the post-development condition. The depth of storage across the site needed to maintain the pre-development discharge rate using retention is 12 mm (0.48 in). Equation 10-7 shows that this is equivalent to a volume of 321 m^3 (0.26 acre-feet). Using detention, the required depth of storage across the site is 8 mm (0.3 in), or using Equation 10-7, a volume of 194 m^3 (0.16 acre-feet).

Storage Volume (acre-feet) = Drainage Area (acres) x Depth of Storage (feet) **Equation 10-7**

The soils are HSG B; therefore, they have good potential for infiltration and the use of retention is appropriate. Hybrid designs that use both retention and detention are intended for soils with poor infiltration capacity (HSG C and HSG D). The use of retention will also encourage recharge and maintain the water balance for the site.

A site may be required not only to maintain the pre-development peak discharge rate, but to maintain the pre-development runoff *volume* as well. The total storage volume required to maintain the pre-development runoff volume can be calculated using Chart 3 in Appendix D, and in this example it equals 11 mm (0.42 in). This is less than the volume needed to maintain the pre-development peak discharge rate (13 mm [0.48 in,] calculated above). Although maintaining the pre-development runoff volume is not a requirement in this case study, this calculation illustrates the feasibility of maintaining the pre-development recharge and runoff characteristics of the site (i.e. peak discharge *and* volume) for frequently occurring storm events up to and including the 2-year 24-hour storm. Therefore, there is full hydraulic and hydrologic control of small-scale, frequently-occurring storms.

10-2.8 **Selection of Appropriate IMPs.** The retention storage volume calculated above, 321 m^3 (0.26 acre-feet,) was used as the total storage volume to be distributed between the selected IMPs. The selected LID components include bioretention cells, bioretention swales, and tree box filters. A ponding depth of 305 mm (12 in) was used to size each of the bioretention devices. Using Equation 10-8, the total area required for bioretention is approximately 1050 m^2 (11,300 sq. ft). Accounting for the volume of runoff that can be stored in the pore spaces in the bioretention media will further decrease the required storage area.

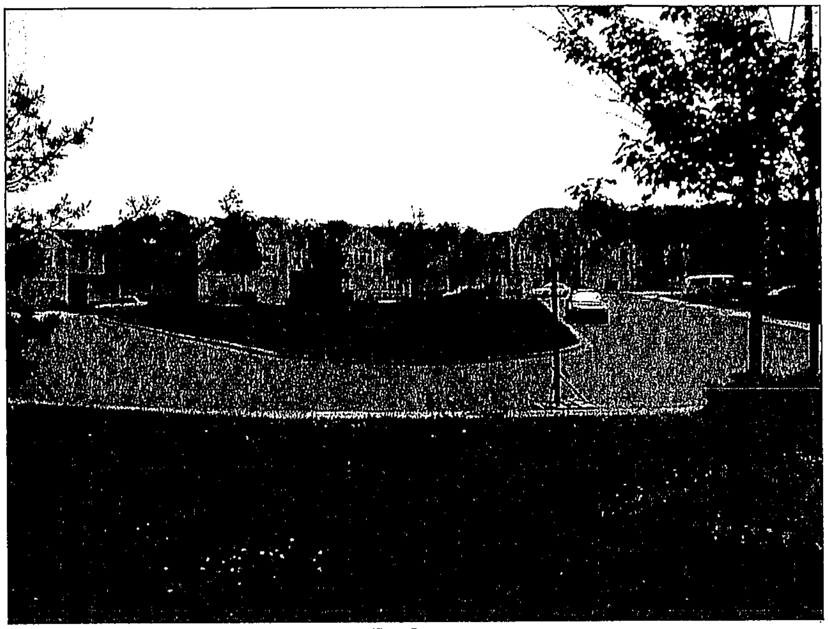
Bioretention Area = Storage Volume ÷ Bioretention Depth **Equation 10-8**

[44] PGDER, 2000b.

These features have been located to intercept and manage the stormwater drainage in small areas. The storm drain pattern remains the same as in the conventional system and provides adequate conveyance. Because of the runoff volume and peak reductions achieved by the LID site design and IMPs, a smaller storm drain diameter can be used if desired.

Figure 10-8 illustrates that the storage volume required to maintain the pre-development 2-year 24-hour peak discharge can be met by using distributed stormwater management. These components can be maintained by the residents, with the exception of the tree box filter. All of the facilities can be maintained by landscape maintenance crews, with minimal training. Figures 10-9 to 10-14 illustrate how the LID features can be incorporated into a residential development.

Figure 10-9. Street Island Modifications



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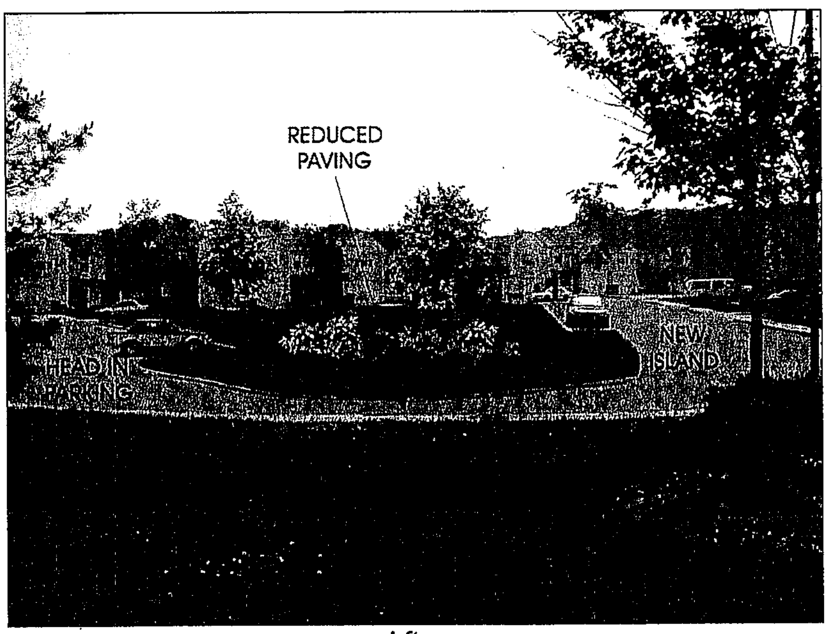
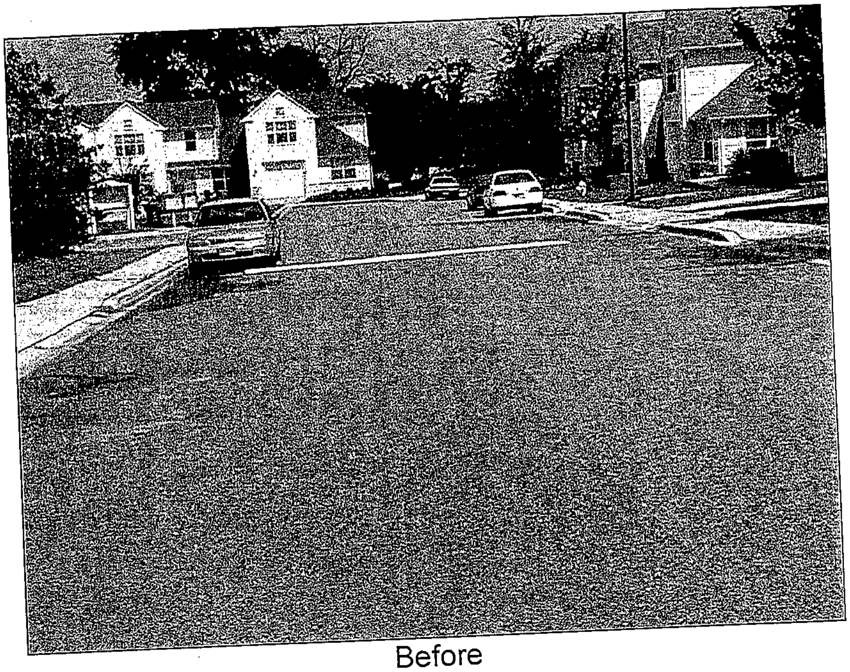


After

Figure 10-10. Street Alterations



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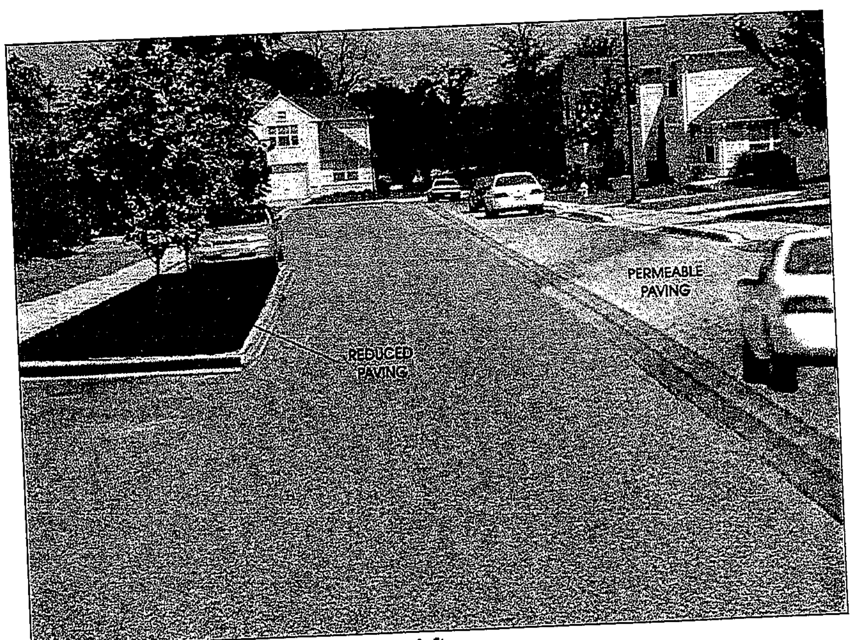

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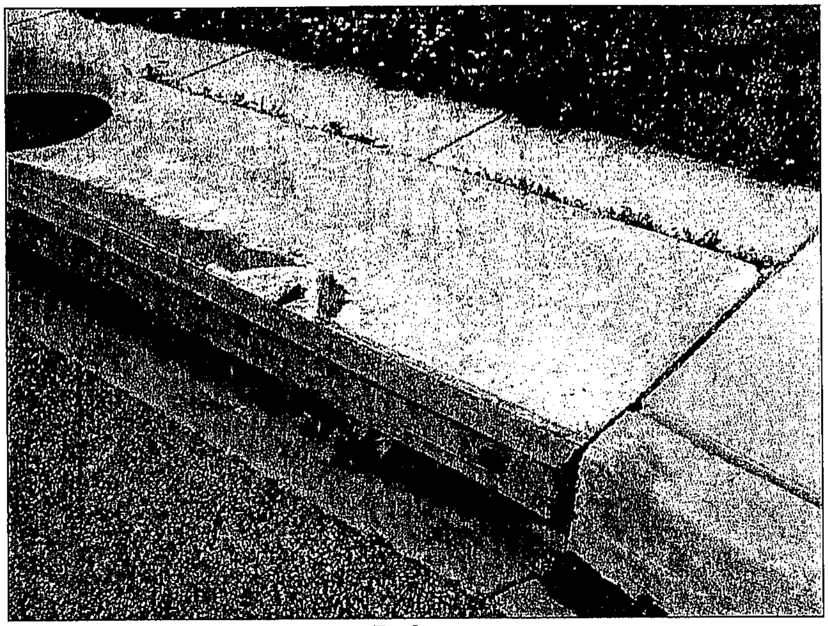
Figure 10-11. Trash Rack



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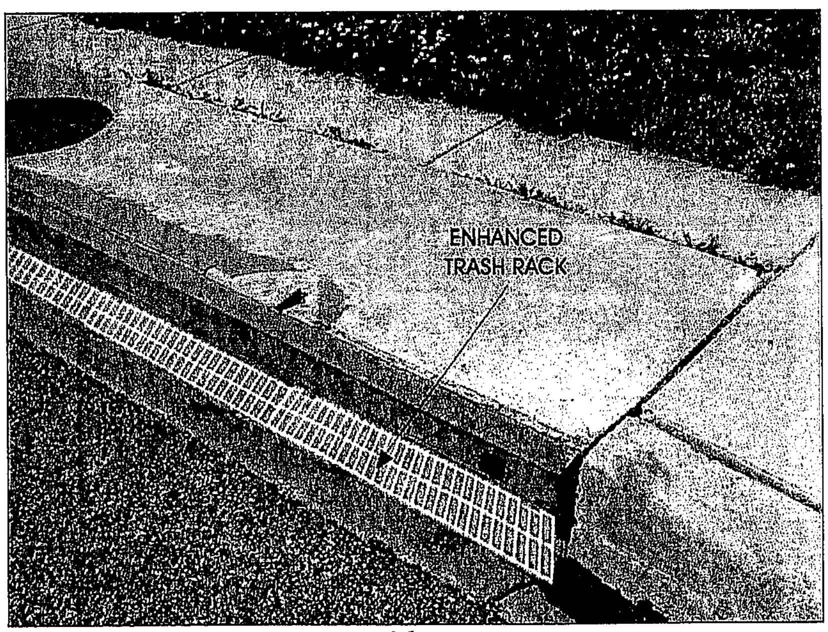

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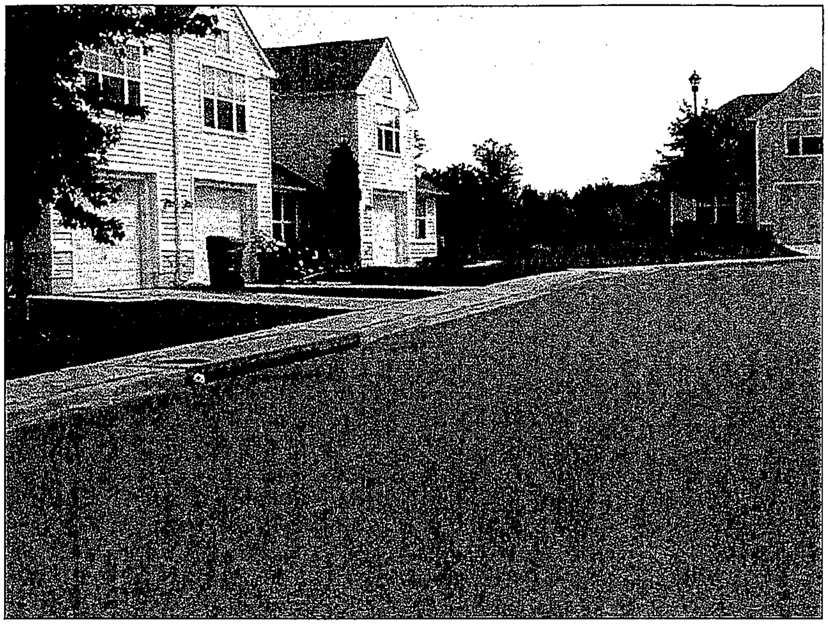
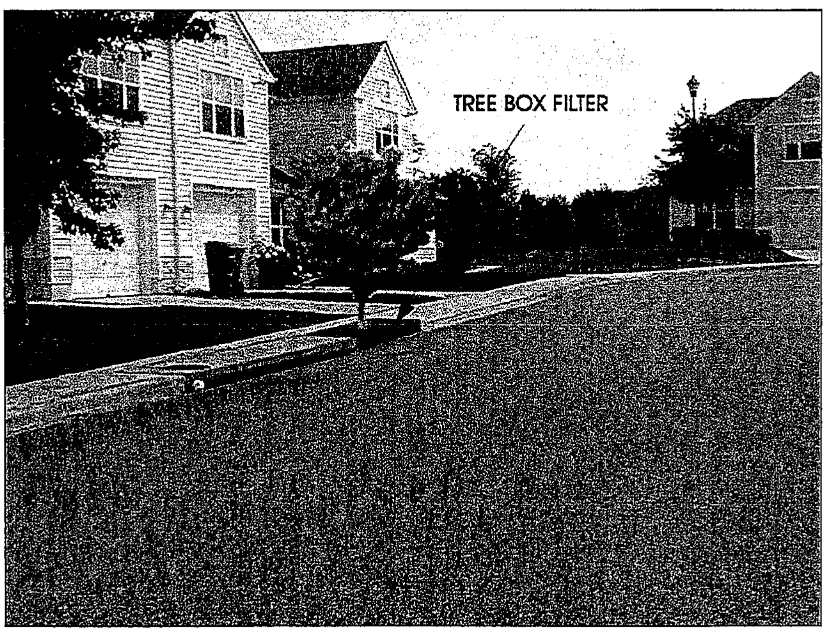
Figure 10-12. Tree Box Filter

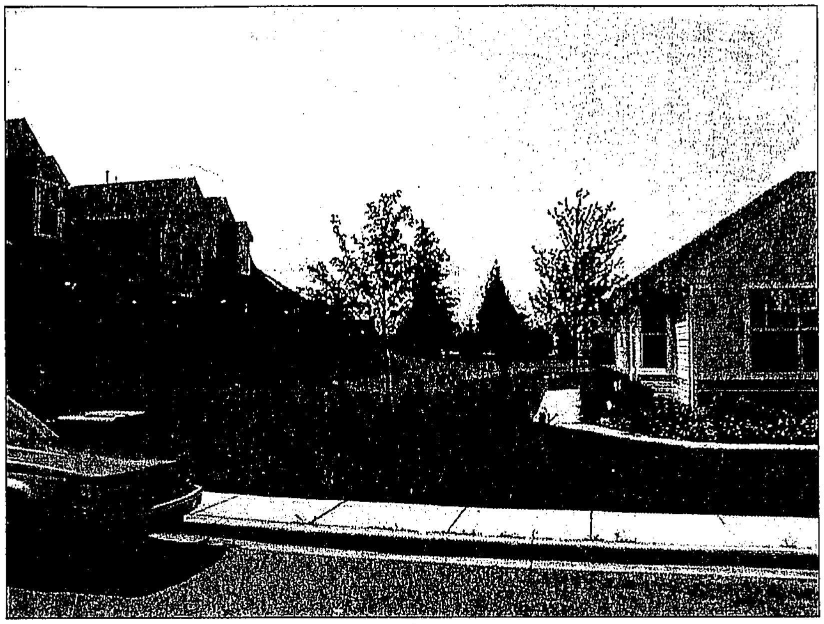


Before



After

Figure 10-13. Bioretention (Rain Garden)



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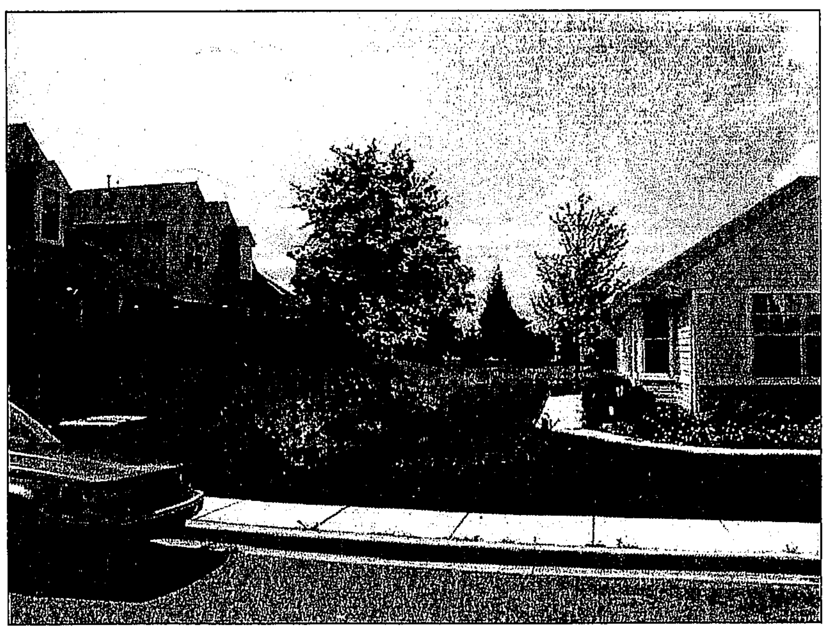
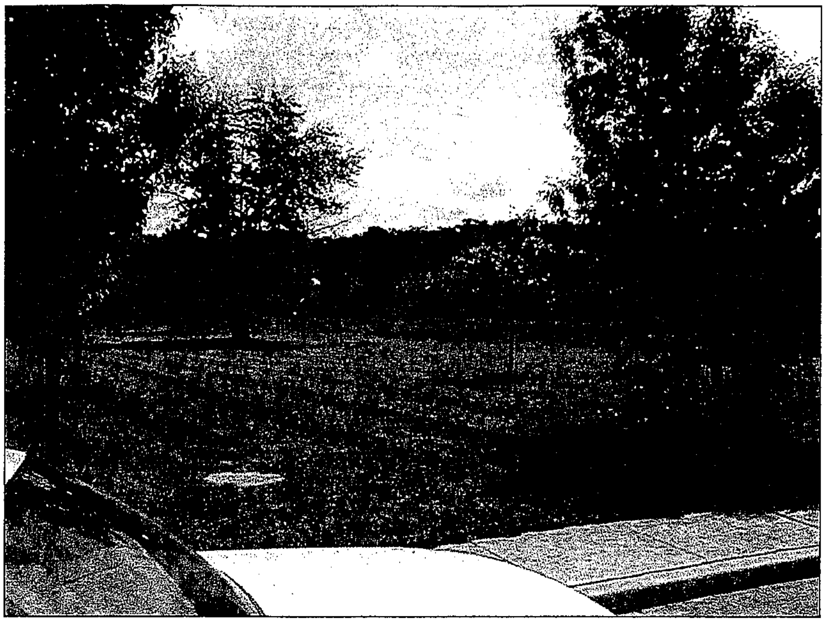


After

Figure 10-14. Reforestation



Before

After

10-2.9 **WATER QUALITY CALCULATIONS.** There are a variety of strategies and methods available to provide water quality control. One conventional approach is to capture a certain volume of runoff and hold it in a detention pond to allow pollutants to settle out of the water. A common regulatory requirement is to store the first 13 mm (0.5 in) of runoff from impervious areas (e.g. roofs, pavement or walks).[45] Based on this requirement and the fact that there are 0.85 ha (2.1 acres) of impervious area in the proposed development, 111 m^3 (0.09 acre-feet) of water quality storage is needed. Since this is less than the total retention storage requirement of 321 m^2 (0.26 acre-feet,) the water quality storage volume is already contained in the proposed design.

Many LID components use the biological, chemical and physical processes of plant and soil interactions to filter and treat pollutants. The effectiveness of these components can be measured in terms of a relative reduction in pollutant concentration or a reduction in the total mass of the pollutant that reaches the receiving waters annually. For this method, the reduction is based on the removal efficiency and flow rates rather than a storage volume. A detailed analysis of the combined effectiveness of the LID components will demonstrate, in some cases, that a storage volume for water quality is not necessary.

10-2.10 **CONCLUSION.** This case study has shown how LID can be incorporated into the design of a residential housing development. The use of LID practices has eliminated the need for a traditional stormwater detention pond, thereby reducing the disturbance to existing forested area. The retention of this forested buffer will in turn reduce impacts to the wetland and receiving waters. The need for piped stormwater conveyances has been eliminated. The LID approach has the added benefit of improving the aesthetics of the development and can provide opportunities for community involvement in the protection and maintenance of the local environment.

[45] Novotny and Olem, 1994.

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APPENDIX B

GLOSSARY: ACRONYMS AND ABBREVIATIONS

ADA	Americans with Disabilities Act
BMP	Best Management Practice
CN	Curve Number
CSO	Combined Sewer Overflow
CWA	Clean Water Act
DoD	Department of Defense
EO	Executive Order
EPA	Environmental Protection Agency
EQI	Environmental Quality Initiative
FHWA	Federal Highway Administration
HEC	Hydraulic Engineering Center
IMP	Integrated Management Practice
LEED	Leadership in Energy and Environmental Design
LID	Low Impact Development
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NURP	Nationwide Urban Runoff Program
P2	Pollution Prevention
PGDER	Prince George's County Department of Environmental Resources
RBP	Rapid Bioassessment Protocols
SCS	Soil Conservation Service
SPCC	Spill Prevention, Control, and Countermeasures
SWMM	Storm Water Management Model
T_c	Time of concentration
TCT	Tilled Compost-Amended Turf
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids

APPENDIX C

SUPPORTING CALCULATIONS FOR SECTION 10-2

Exhibit A. TR-55 Time of Concentration Calculation for Existing Condition

TIME OF CONCENTRATION AND TRAVEL TIME — Version 2.10

Project : RESIDENTIAL CASE STUDY — User: — Date: 07-11-2003
County : — State: — Checked: ____ — Date: ________
Subtitle: EXISTING CONDITION

Subarea #1 - 1

Flow Type	2 year rain	Length (ft)	Slope (ft/ft)	Surface code	n	Area (sq/ft)	Wp (ft)	Velocity (ft/sec)	Time (hr)
Sheet	3	100	.02	E					0.169
Shallow Concent'd		565	.02	U					0.069

Time of Concentration = 0.24*

--- Sheet Flow Surface Codes ---

A Smooth Surface	F Grass, Dense
B Fallow (No Res.)	G Grass, Burmuda
C Cultivated < 20 % Res.	H Woods, Light
D Cultivated > 20 % Res.	I Woods, Dense
E Grass-Range, Short	J Range, Natural

--- Shallow Concentrated ---
--- Surface Codes ---
P Paved
U Unpaved

Exhibit B. TR-55 Time of Concentration Calculation for Proposed Condition

TIME OF CONCENTRATION AND TRAVEL TIME — Version 2.10

Project : RESIDENTIAL CASE STUDY — User: — Date: 07-11-2003
County : — State: — Checked: ____ — Date: ________
Subtitle: PROPOSED CONDITION

Subarea #1 - 1

Flow Type	2 year rain	Length (ft)	Slope (ft/ft)	Surface code	n	Area (sq/ft)	Wp (ft)	Velocity (ft/sec)	Time (hr)
Sheet	3	100	.02	E					0.169
Shallow Concent'd		150	.02	U					0.018
Open Channel		415						4.0	0.029

Time of Concentration = 0.22*

--- Sheet Flow Surface Codes ---

A Smooth Surface	F Grass, Dense
B Fallow (No Res.)	G Grass, Burmuda
C Cultivated < 20 % Res.	H Woods, Light
D Cultivated > 20 % Res.	I Woods, Dense
E Grass-Range, Short	J Range, Natural

--- Shallow Concentrated ---
--- Surface Codes ---
P Paved
U Unpaved

Exhibit C. TR-55 Detention Basin Storage Volume Calculation for Proposed Condition, Conventional Site Design

```
                    TR-55 STORAGE VOLUME FOR DETENTION BASINS        Version 2.10

                       >>>>> Identification Data <<<<<           Date 04-23-2004

Project RESIDENTIAL CASE STUDY

Subtitle PROPOSED CONDITION (CONVENTIONAL)

                           >>>>> Basic Data <<<<<

Drainage Area 6.5 Acres

Rainfall-Type (I,IA,II,III) II

Rainfall Frequency 2 years          24-Hour Rainfall 3 inches

Runoff 1.25 inches                  Runoff Curve Number 80

Peak Inflow 9.3451 cfs              Peak Outflow 2.3229 cfs

   Detention Basin Storage Volume:    0.52 inches   or   0.3 acre feet
```

```
                    TR-55 STORAGE VOLUME FOR DETENTION BASINS        Version 2.10

                       >>>>> Identification Data <<<<<           Date 04-23-2004

Project RESIDENTIAL CASE STUDY

Subtitle PROPOSED CONDITION (CONVENTIONAL)

                           >>>>> Basic Data <<<<<

Drainage Area 6.5 Acres

Rainfall-Type (I,IA,II,III) II

Rainfall Frequency 10 years         24-Hour Rainfall 5 inches

Runoff 2.89 inches                  Runoff Curve Number 80

Peak Inflow 22.638 cfs              Peak Outflow 10.328 cfs

   Detention Basin Storage Volume:    0.85 inches   or   0.5 acre feet
```

Exhibit D. TR-55 Detention Basin Storage Volume Calculation for Proposed Condition, LID Site Design

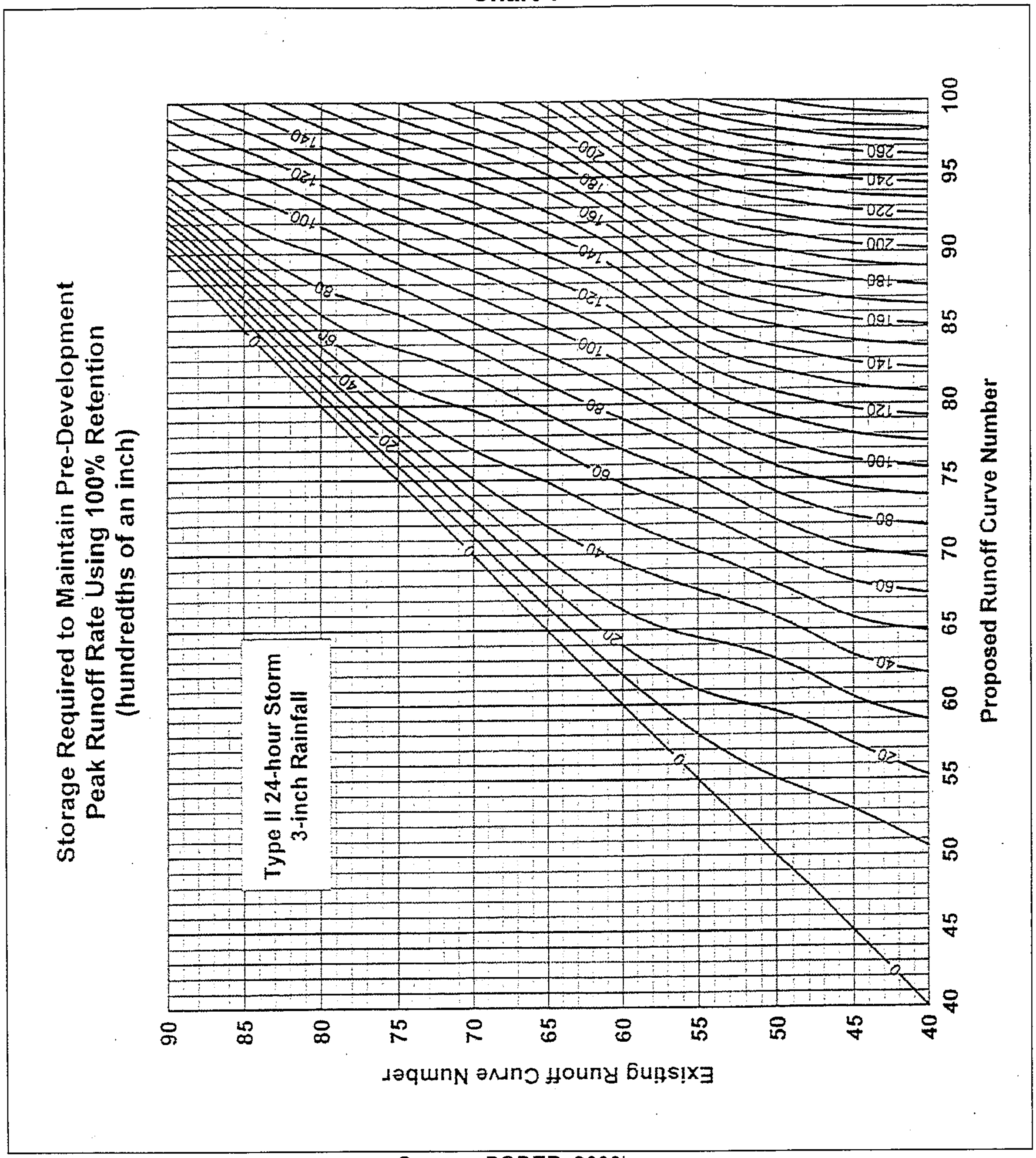
```
TR-55 STORAGE VOLUME FOR DETENTION BASINS        Version 2.10

>>>>> Identification Data <<<<<                  Date 04-23-2004

Project RESIDENTIAL CASE STUDY

Subtitle PROPOSED CONDITION (LID)

>>>>> Basic Data <<<<<

Drainage Area 6.5 Acres

Rainfall-Type (I,IA,II,III) II

Rainfall Frequency 2 years        24-Hour Rainfall 3 inches

Runoff .857 inches                Runoff Curve Number 73

Peak Inflow 5.8163 cfs            Peak Outflow 2.3229 cfs

Detention Basin Storage Volume:   0.28 inches  or  0.1 acre feet
```

```
TR-55 STORAGE VOLUME FOR DETENTION BASINS        Version 2.10

>>>>> Identification Data <<<<<                  Date 04-23-2004

Project RESIDENTIAL CASE STUDY

Subtitle PROPOSED CONDITION (LID)

>>>>> Basic Data <<<<<

Drainage Area 6.5

Rainfall-Type (I,IA,II,III) II

Rainfall Frequency 10 years       24-Hour Rainfall 5 inches

Runoff 2.28 inches                Runoff Curve Number 73

Peak Inflow 16.652 cfs            Peak Outflow 10.328 cfs

Detention Basin Storage Volume:   0.53 inches  or  0.3 acre feet
```

APPENDIX D

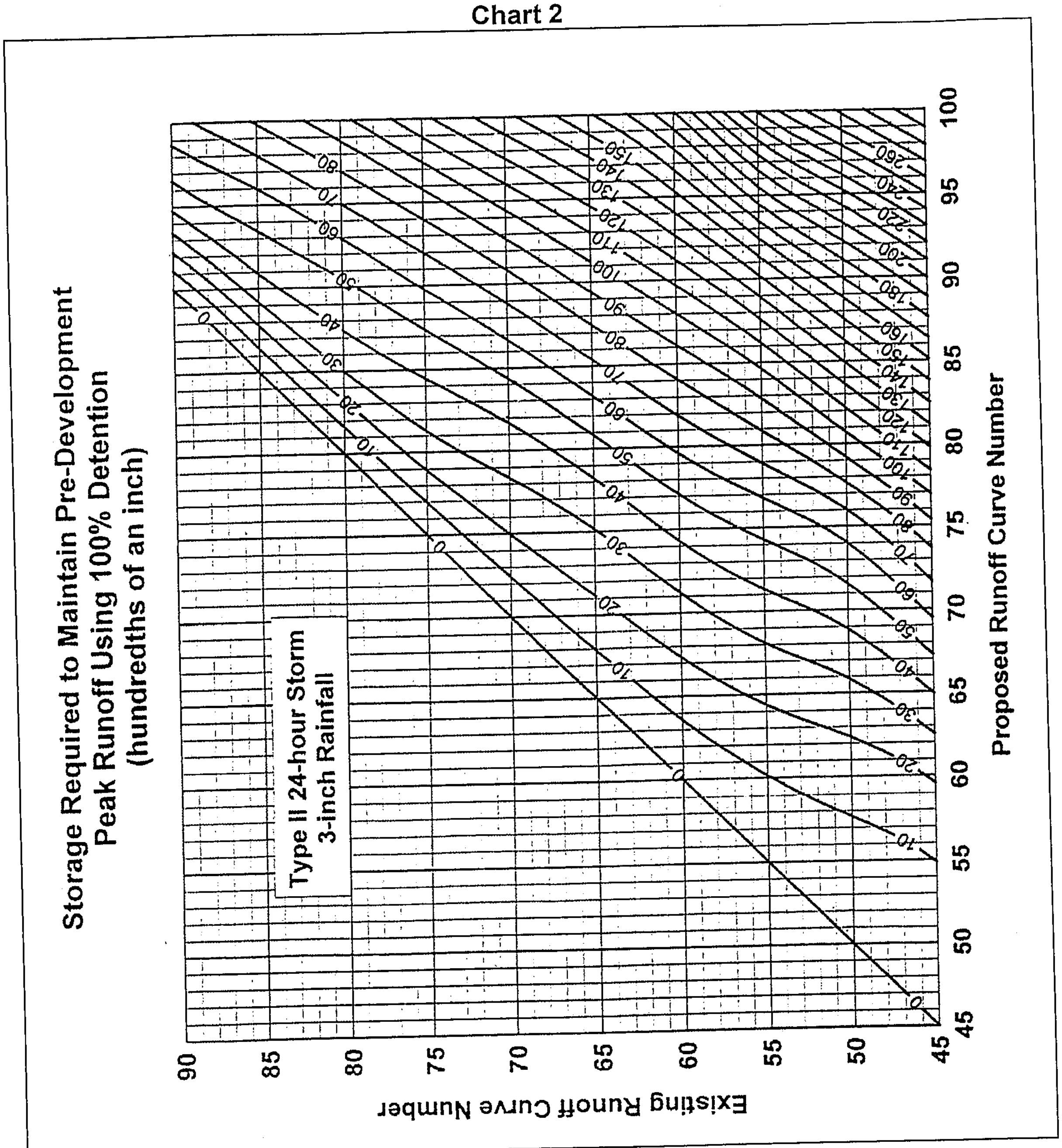
LID DESIGN CHARTS

Chart 1



Source: PGDER, 2000b.

Chart 2



Source: PGDER 2000b.

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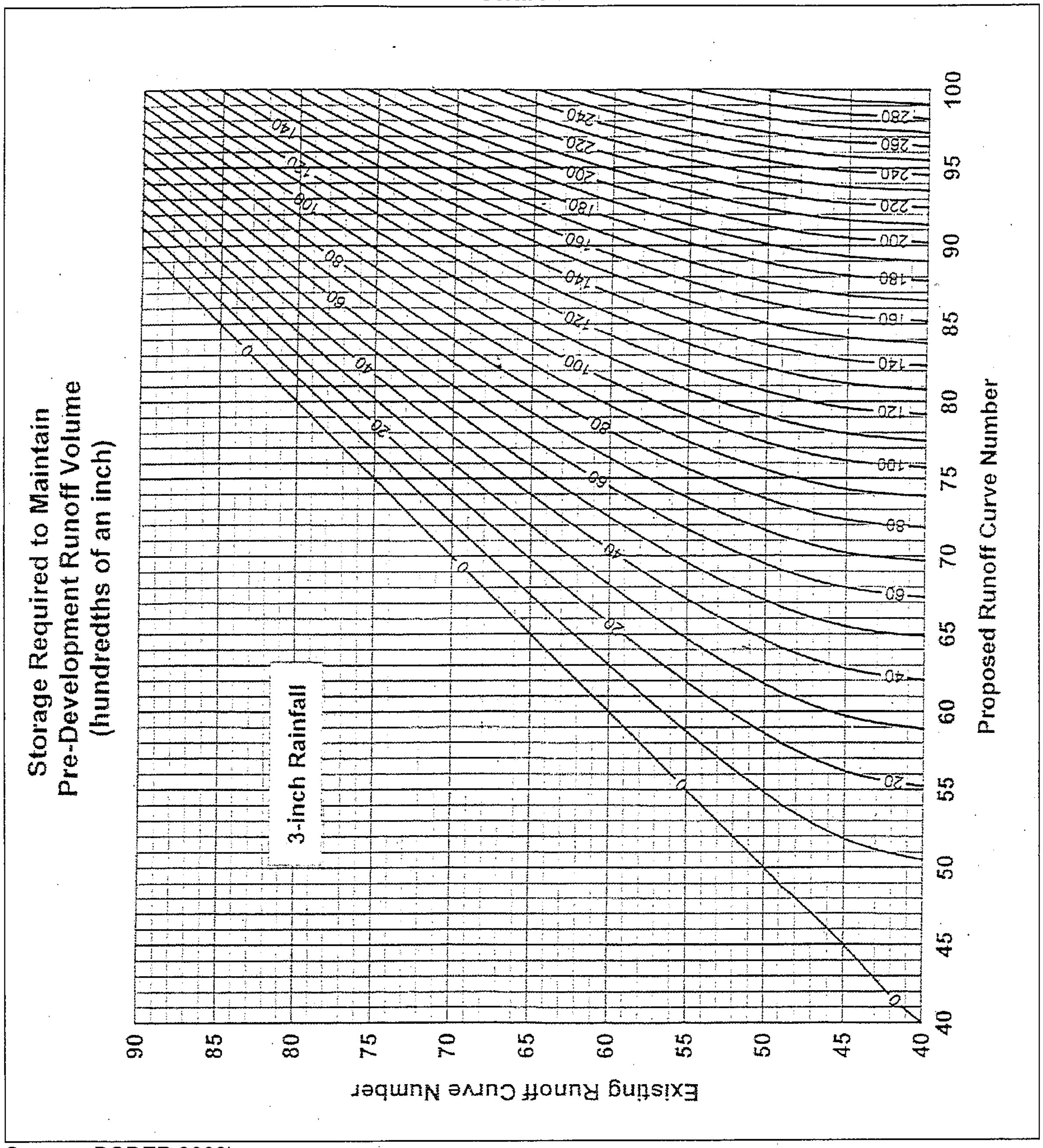
Chart 3

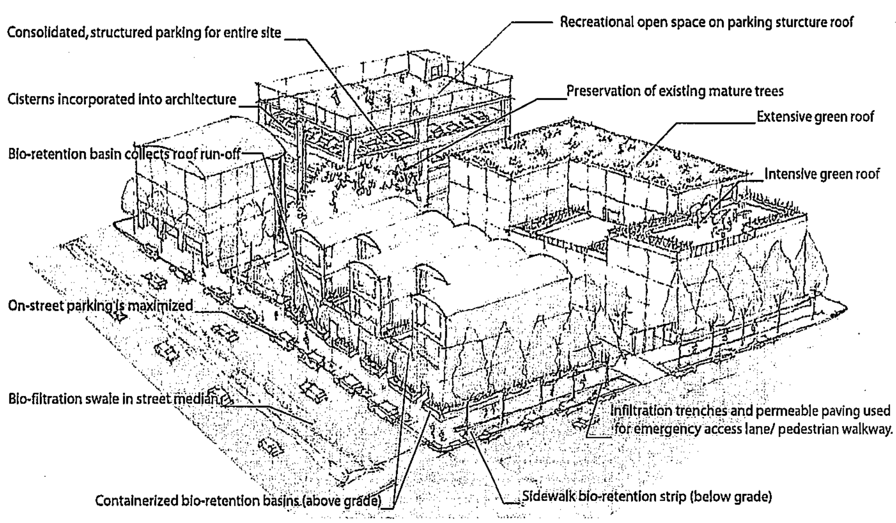


Source: PGDER 2000b.

Stormwater Guidelines for Green, Dense Redevelopment

Stormwater Quality Solutions for the City of Emeryville

December 2005



Prepared by: Community Design + Architecture *with*

Nelson\Nygaard Consulting Associates

Philip Williams Associates

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Stormwater Guidelines for Green, Dense Redevelopment

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Prepared by: Community Design + Architecture *with*
Nelson\Nygaard Consulting Associates
Philip Williams Associates

TABLE OF CONTENTS

I. INTRODUCTION

I.I What is the Purpose of the Guidelines?

I.I.I Who and What Benefits?

Cities must now require development and redevelopment projects to treat stormwater and these guidelines offer ways to meet the requirements in Emeryville, where development patterns are dense, some soils are impermeable or contaminated, and the water table is high. In the past decade, the City of Emeryville has earned a national reputation as a pioneer in reclaiming, remediating, and redeveloping its decaying industrial lands. A massive brownfields pilot program has resulted in a dramatic economic turnaround for the City and has succeeded in attracting new business and new residents to the city. Through an Environmental Protection Agency (EPA) grant, the City is now addressing its next challenge – to meet new standards for water quality and improve the general environmental sustainability of continued revitalization efforts.

These Guidelines, geared specifically to developers and designers, will provide a vision for integrating green stormwater treatment into the site planning and building design of new development. Additional efficiencies in development will also be gained from pedestrian-friendly parking strategies. The parking and green design solutions range from shared district parking facilities to green roofs to containerized bio-retention gardens. All are tailored for Emeryville's unique context: heavily urbanized sites, compacted or even contaminated soils, and a high water table. Because these Guidelines includes a thorough numeric, hydraulic sizing methodology for various facility types, it will enable City staff, planners, designers, and developers to implement sustainable design on many scales throughout Emeryville. Implementation of the guidelines will allow Emeryville to be increasingly competitive in attracting research and knowledge based businesses and develop additional housing opportunities for those interested in Emeryville's urban lifestyle.

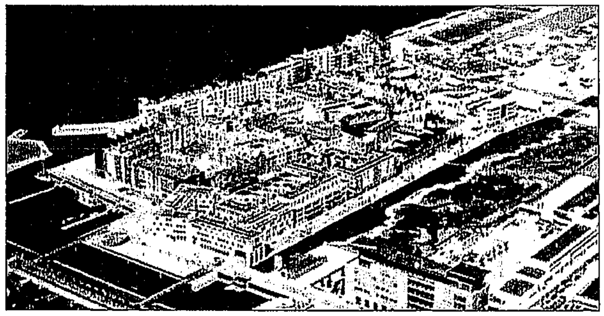


Figure 1-1: Aerial photo of green, dense redevelopment on a former industrial site in Malmo, Sweden. This development was created as part of the Bo01 Expo, which showcased sustainable and green design.

1.2 What Is "Green Dense Redevelopment"?

1.2.1 Definition of Terms

These Guidelines use the term "Green Dense Redevelopment" to describe redevelopment and infill projects that create vibrant urban neighborhoods and provide ecological benefits. The thinking behind "green dense redevelopment" is that urban infill projects can benefit water resources by directing growth away from the undeveloped portions of a watershed.

In addition, these projects can be designed to benefit water quality on a site level by reducing the amount of paved surface that exacerbates runoff and by providing on site stormwater treatment facilities. In this sense, green dense redevelopment should contain less impervious paved surface and more pervious, landscaped surfaces than conventional development. Because of their important role in reducing runoff volumes and filtering contaminants, plants are also a critical component of green dense redevelopment. This redevelopment strategy will involve more landscaped areas compared to traditional development. Also, plantings and landscaping will be designed differently to enable them to serve as integral components in the stormwater treatment process, rather than as ornaments.

The types of "dense" development envisioned in these Guidelines include mixed use (combinations of residential, office and retail) and residential projects with densities of 12 units per acre or higher. For the purposes of this workbook, the "green" components of a project may include a range of land use and parking policies, site design strategies, and design details that reduce the amount of impervious surface or provide some degree of stormwater treatment on-site. Many of the "green" design components featured in these Guidelines serve multiple roles, so that "green" often refers to more than stormwater function. Many of these elements play roles in providing green space for recreation, habitat for wildlife, energy savings, improved air quality, reduced heat-island effect, and neighborhood character.

1.2.2 Rethinking the Relationship Between Density and Stormwater

Several studies have found that covering just 10 percent of a watershed's land area with impervious surface can impair hydrological function and water quality within the watershed. Some communities have inferred from this finding that very low-density development is preferable to denser types because on the scale of an individual lot, low-density development may allow the majority of a lot to remain unpaved and unbuilt. Yet this interpretation does not take into consideration the fact that very low-density development requires more impervious coverage off-site, in terms of roads and parking lots, which may increase the amount of impervious surface within the watershed but not on the individual lot.

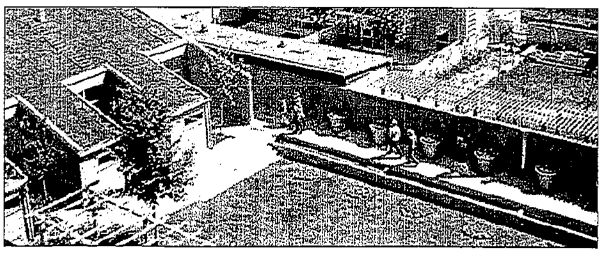


Figure 1-2: Courtyards and rooftops reduce urban runoff while providing attractive green spaces for residents.

The EPA, the Center for Watershed Protection, and other environmental agencies and organizations are reassessing the water quality impacts associated with different development densities. Their research indicates that higher density infill projects may, in fact, provide more water quality benefits than low-density development. The Center for Watershed Protection reported that, "Increasingly, urban redevelopment and infill projects are emerging as a means to help rejuvenate sagging city centers, while simultaneously providing opportunities for more environmentally-friendly growth."

"Protecting Water Resources with Higher Density Development," published by the EPA, dispels a number of myths and reexamines the underlying assumptions regarding the relationship between density and water quality. It raises five basic points in its critique of conventional arguments for low-density development:

- Higher density does not necessarily mean more impervious surface—multiple units in a compact arrangement may reduce the building footprints and thus, result in less impervious coverage (per unit) than stand-alone units dispersed across the landscape.
- Not all "pervious" surfaces are equal—many disturbed surfaces that appear pervious (like lawns) may be compacted, which greatly reduces their ability to infiltrate runoff.
- Low-density development often requires more off-site impervious infrastructure (roads, parking lots, etc.)
- The rule of thumb that 10 percent impervious cover will impair a watershed should be assessed on the scale of the watershed—not on the individual site.
- Low density development does not reduce impacts—it just spreads them out.

The arguments for dense green development contradict conventional notions that cities are inherently "bad" for water quality. If properly designed, high-density development can, in fact, benefit its natural environment, including water resources.

1.3 Connections Between the Guidelines and Other Efforts and Policies

1.3.1 Federal: Clean Water Act Amendment, Surface Pollutants and the NPDES

The 1972 Clean Water Act was amended in 1987 requiring cities to apply for the same kind of NPDES (National Pollutant Discharge Elimination System) permits for their municipal "separate" storm sewers (as opposed to "combined" systems where storm runoff is treated with sewage) as they would for regular outfalls from sewage systems.

The focus of the NPDES Municipal Separate Storm Sewer System permit is to eliminate pollutant discharges from municipal stormwater into public waters. Local municipalities take an active role in the permitting process to devise stormwater management plans that reduce identified pollutants for specific water bodies. Emeryville is a member of the Alameda County Clean Water Program (ACCWP), which has a joint NPDES permit. The permit requires member jurisdictions to require developers to design projects to treat stormwater.

1.3.2 ACCWP's NPDES Permit

A 1987 revision to the federal Clean Water Act requires cities with more than 100,000 people and smaller cities located in large metropolitan areas to control the amount of pollution entering local storm drain sewer systems. In 1989, a consortium of 17 county and city agencies established the Alameda Countywide Clean Water Program (ACCWP) to facilitate compliance with these regulations. Guidelines for managing, monitoring, and reducing urban runoff were established for the Clean Water Program through the National Pollutant Discharge Elimination System (NPDES) permit to discharge municipal storm waters. This NPDES permit requires that development projects treat approximately 85 percent of annual rainfall, which in the Bay Area is roughly equivalent to a 1-inch storm. The ACCWP developed a Storm Water Management Plan to meet objectives from both: 1) the NPDES permit and; 2) the Bay Basin Plan which was developed by the San Francisco Regional Water Quality Control Board (RWQCB) to prevent urban runoff pollution and to help restore the health of local creeks and San Francisco Bay.

Under the ACCWP private development projects are broken down into two groups: Group 1 are projects creating or replacing more than one acre of impervious surface; and Group 2 are projects creating or replacing more than 10,000 square feet of impervious surface. Implementation start dates vary for each group:

Group 1: Project applications and amendments received between February 15, 2005 and August 14, 2006, or projects that have not submitted a complete application as of February 15, 2005 with one acre or more impervious surface, must comply with hydraulic sizing design criteria for stormwater quality treatment. Projects that have submitted complete applications before February 15, 2005 are considered "deemed complete" and are not required to comply with hydraulic sizing design criteria for stormwater treatment. Projects with Planning Commission approval that propose changes on or after February 15, 2005 requiring Planning Commission re-approval must comply with the hydraulic sizing design criteria for stormwater treatment.

Group 2: Project applications and amendments received after August 15, 2006, or projects that have not submitted a complete application as of August 15, 2006 must comply with hydraulic sizing design criteria for stormwater quality treatment. Projects that have submitted complete applications before August 15, 2006 with 10,000 square feet or more impervious surface are considered "deemed complete" and are not required to comply with hydraulic sizing design criteria for stormwater treatment. Projects with Planning Commission approval that propose changes on or after August 15, 2006 requiring Planning Commission re-approval must comply with the hydraulic sizing design criteria for stormwater treatment.

These guidelines serve as one part of the City of Emeryville's compliance with the requirements associated with the joint NPDES permit. The City prefers vegetative design solutions such as those described in these guidelines rather than mechanical solutions. This is because vegetative solutions treat stormwater more effectively, involve easier maintenance and inspection, improve air quality and provide green aesthetics. Therefore, the City desires to see vegetative solutions whenever possible. Developers of projects subject to numerical treatment requirements shall be required to retain a qualified stormwater consultant to design on-site treatment measures. The consultant shall either be one that is listed by the Bay Area Stormwater Management Agencies Association ("BASMAA") as qualified in stormwater treatment design (www.basmaa.org/documents, Qualified Post-Construction Consultants List), or a consultant that demonstrates similar qualifications to those on the BASMAA List. The stormwater treatment design consultant shall make a good faith effort to meet the entire treatment requirement using vegetative solutions. If the stormwater treatment design consultant concludes that vegetative solutions are not feasible due to site characteristics, building uses or other legitimate reasons, and the City concurs, the City will consider allowing on-site mechanical solutions. In some cases, upon recommendation of the stormwater treatment design consultant, a combination of vegetative and mechanical solutions may be allowed. If mechanical solutions are utilized, the mechanism must be approved by the City, and the developer must demonstrate that the mechanical design will remove fine sediments and dissolved metals as well as trash and oil.

1.3.3 Resources from Agencies

The ACCWP has published a booklet titled *Protecting Water Quality in Development Projects: A Guidebook of Post-Construction BMP Examples.* It can be obtained at www.cleanwaterprogram.org and at www.basmaa.org, the website for the Bay Area Stormwater Management Agencies Association (BASMAA). The BASMAA website also has a list of qualified post-construction consultants, who can help design sites for stormwater treatment. The California Stormwater Quality Association (CASQA) has published a book titled *California Stormwater Best Management Practices (BMP) Handbook: New Development and Redevelopment* (CASQA handbook). It can be downloaded from www.cabmphandbooks.com.

1.4 How to Use These Guidelines

The Guidelines for Green Dense Redevelopment are intended for a variety of users. The chapters are summarized below, to enable different users to identify and locate the information they need.

Developers and Citizens Doing Site Design:

- The regulatory framework
- A method for matching a particular design solution with a development type or element
- A method for effective numeric sizing of a particular design solution
- Conceptual design solutions that will need to be detailed for a specific site

Elected Officials and Public Agency Engineers and Planners:

- Integrating solutions, layering uses and understanding the big picture

Chapter Summaries

1. Introduction

This chapter provides a user's guide to navigating through these Guidelines and an overview of its contents.

2. Goals

This chapter discusses the unique approach that these guidelines are taking to achieve goals related to both parking and stormwater quality.

3. Concepts

A basic understanding of a few key terms, principles, and processes is necessary before the guidelines can be implemented.

4. Designing for the Emeryville Context

These Guidelines is specific to Emeryville's unique environment, which is described in this chapter.

5. Innovative Parking Solutions

This chapter presents a "toolbox" of parking solutions intended for both the City and private developers.

6. Stormwater Management Design Solutions (BMP's)

This chapter describes a range of stormwater design solutions that could be applicable to Emeryville projects.

7. Selecting and Sizing Stormwater Design Solutions

This chapter explains how to integrate stormwater design solutions into the site design process. Also included are detailed instructions on using the accompanying Design Solution Sizing Spreadsheets.

8. Case Studies

This chapter presents case study examples of key components of the parking approaches and design solutions.

9. Appendixes

A glossary of terms, bibliography, credits, and technical notes are presented in the final chapter.

2. GOALS

Environmental sustainability–best defined as the identification, preservation, restoration, and enhancement of natural systems–is increasingly becoming an important public and regulatory concern. Equally so, "Smart Growth" principles involving compact, mixed-use development, preservation of land through infill practices, and the creation of walkable, safe and attractive neighborhoods that provide for the variety of transportation choices are also at the forefront of contemporary planning and urban design.

Establishing the *Emeryville Design Guidelines for Green Dense Redevelopment* understands that solutions to ecological health are found in an integrated approach to urban development that acknowledges needs for a healthy habitat for humans and other species, and the requirements of modern urban living. One must understand that the environment, urban or otherwise, is not a collection of discrete units; rather everything overlaps and everything is connected. In order to have any meaningful impact on complicated problems, solutions must understand this premise.

The following represent a preliminary set of goals for these Guidelines, developed through discussion with City staff and the public through a workshop format.

2.1 Improve Water Quality

The water resources of a community are only as healthy as the water that flows through it. Efforts are needed to improve the quality of stormwater runoff through the related processes of retention and infiltration. A retention facility captures and temporarily holds stormwater runoff, allowing it to infiltrate into the soils (i.e. be absorbed by the soils). Bio-retention and bio-filtration are processes closely related to retention and infiltration but incorporate plants to filter pollutants and increase the porosity of the soils. New development, including roads, must reduce impervious surfaces, allowing rain to infiltrate as near as possible to where it falls (typically referred to as "ubiquitous infiltration"). The unique conditions in Emeryville, however, generally preclude direct infiltration into the groundwater, thus requiring a subsurface collection system. When water is conveyed, the flow should go through a process of bio-filtration that enables vegetation to filter and treat runoff.

2.2 Protect Habitat Value

Growth can be accommodated and quality of habitat improved if negative impacts of urban transportation and development are reduced. Strategies should include measures to improve water quality while reducing the overall quantity of urban runoff. Furthermore, protection and enhancement of other natural resources such as wetlands and significant stands of trees and shrubs also improve habitat for wildlife, and have a significant effect on quality of life for people.

2.3 Use Land Efficiently

A city as built-out as Emeryville cannot expand beyond its boundaries, but must utilize Smart Growth infill redevelopment practices in order to increase development potential. Land is essentially a finite resource that necessitates the layering of many uses including alternative infrastructure systems promoting stormwater infiltration, other public utilities, and opportunities for recreation. Efficiently accommodating parking not only reduces overall impervious surface, but also releases land for more intense development.

2.4 Embrace Natural Processes

Modern American urban development has slowly begun to understand the benefits of considering environmental factors in the design, but typically to the minimum required by the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA). New development should more fully consider its impact on stormwater filtration, as well as the overall social life of the community. Solutions should be grounded in the appreciation that the natural process of stormwater infiltration (with subsurface collection on contaminated sites) and natural drainage patterns are optimal for providing multiple benefits including attractive pedestrian environments and recreational open space. Furthermore, careful implementation and maintenance of natural processes is affordable.

2.5 Provide Cost-Effective Solutions

Green redevelopment design solutions should be permittable and cost-effective in terms of initial construction, maintenance, and long-term replacement. Design decisions based upon the site characteristics are more efficient when working with, rather than against, natural processes. Cost comparison analysis should be sensitive enough to recognize environmental, social, and quality of life benefits of the green redevelopment design solutions.

2.6 Foster Unique and Attractive Streetscapes and Development

A streetscape design with multiple functions that integrates the "natural" and the "man-made" can provide a unique identity to a community. Green development streetscapes facilitate natural infiltration and therefore have less impervious surfaces such as concrete and asphalt. This allows for greater use of vegetation and other attractive materials such as crushed stone and pavers that can be selected to create an identifiable community character. This design approach, together with a properly funded maintenance program can provide a streetscape that reduces the negative impacts typically associated with streets: visual quality, noise pollution and traffic congestion, and ensures long-term stewardship of natural resources.

3. CONCEPTS

3.1 Introduction

The basic concepts of stormwater treatment are not complicated. The goal is to restore the hydrological cycle as much as possible. This means intercepting the water that falls from the sky before it reaches the ground, and then getting as much of the rest into the ground as quickly as possible. What does become complicated is the breadth of issues involved once the land becomes urbanized. Addressing all the issues can be somewhat daunting.

3.2 The Hydrologic Cycle and Effects of Urbanization

An urban or urbanizing watershed is one in which impervious surface covers a considerable portion of the land area. With urbanization, natural flow paths in the watershed are typically replaced or supplemented by paved gutters, storm sewers, or other elements of artificial drainage.

As the natural landscape is paved over, a chain of events takes place that typically ends in degraded water bodies. This chain begins with alterations to the hydrologic cycle and the way water is transported and stored.

Urbanization changes a watershed's response to precipitation. The most common effects are reduced infiltration and decreased travel time, which significantly increase peak discharges and runoff volumes. The amount of runoff is determined primarily by the amount of precipitation and by infiltration characteristics related to soil type, soil moisture, antecedent rainfall, land surface cover type, impervious surfaces, and surface retention. Travel time is primarily determined by slope, length of flow path, depth of flow, and roughness of the flow surface. Peak discharges are based on the relationship of these parameters and on the total drainage area of the watershed, the location of development, (which includes encroachment into the floodplain and loss of wetlands) the effect of any flood control structures or other human constructed storage facilities, and the distribution of rainfall during a given event.

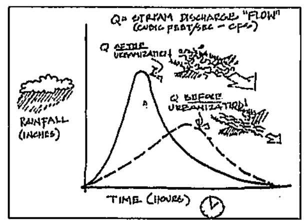


Figure 3-1: Urbanization results in a sharper peak on the storm hydrograph.

The amount, timing, and duration of stream flow events can be visually presented in a hydrograph. A hydrograph is a plot comparing the rate of runoff against time for a point on a channel or hillside.

3.2.1 The Earth as a Sponge ("Normal" conditions: not brownfield)

Infiltration rates of soils vary widely and are affected by subsurface permeability as well as soil intake rates. Soils are classified into four Hydrologic Soil Groups (A, B, C, and D) according to their minimum infiltration rate, which is obtained from bare soils after prolonged wetting. Most urban areas are only partially covered by impervious surfaces; however the soil remains an important factor in runoff estimates. Urbanization has a greater effect on runoff in watersheds with soils having high infiltration rates (i.e. sands and gravels) than in watersheds predominantly of silt and clays, which generally have low infiltration rates. Also, development typically results in the removal of topsoil, generally leaving heavily compacted soils that have a reduced pollutant treatment capacity.

3.2.2 Percentage of Impervious Land as Indicator of Ecological Health

Research indicates that impervious coverage over 30 percent is associated with severe, practically irreversible degradation. Degradation occurs in 5 ways:

- Rainwater is no longer trapped by vegetation to the same extent, thereby increasing runoff.

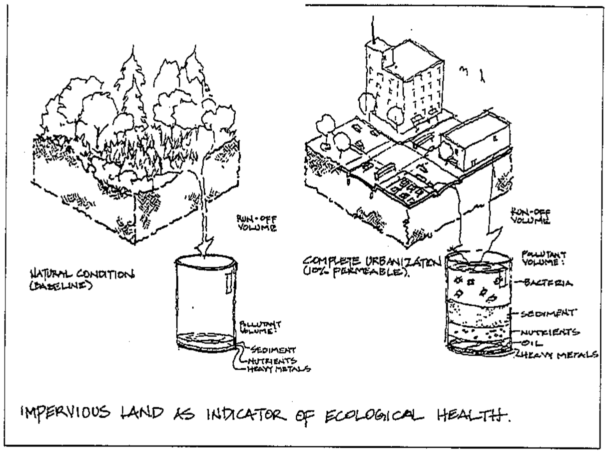


Figure 3-2: As impervious surface increases, so does runoff volume.

- Much of the rainwater is prevented from moving into the soil, where it recharged groundwater, and stream baseflows are thereby reduced.
- Because the larger volume of rainwater cannot infiltrate into the soil, more rainwater runs off thus creating greater flows more frequently. This enlarges the stream channel causing bank erosion and associated reduction of habitat and other stream values.
- Runoff flowing across impervious surfaces collects and concentrates pollutants from cars, roadways, rooftops, lawns, etc. (i.e. "nonpoint" sources) significantly increasing pollution in stream and other waterbodies.
- Impervious surfaces retain and reflect heat, causing increases in ambient air and water temperatures. Increased water temperatures negatively impact aquatic life and oxygen content of water bodies.

The three basic tenets of reducing imperviousness – retaining the natural landscape, minimizing pavement, and promoting natural infiltration to the soil – are simple concepts that can be understood by citizens.

3.2.3 Why is Runoff so Polluting?

For several decades, the nation's environmental laws were aimed at curbing traditional sources of pollution such as raw sewage and industrial waste–referred to as "point" source pollution. Since the 1980s, however, attention has turned to "nonpoint" pollution, which comes from diffuse sources such as roads, roofs, lawns, driveways, parking lots, etc. Nonpoint source pollution is now the number one cause of water quality impairment in the United States, accounting for 50 percent of water problems in the nation's water bodies.

So what exactly is flowing off of yards and streets? An overabundance of nutrients such as nitrogen and phosphorous from fertilizers and animal droppings, although not detrimental to soil, threaten water supplies by producing algae blooms that, upon decaying, rob the water of life-sustaining oxygen. Toxic contaminants like heavy metals and pesticides pose threats to aquatic creatures and humans. Sediment from eroded banks or runoff creates turbidity (murkiness) which can also clog waterways and become carriers of other pollutants, as well as being unsightly. Sediment is also a threat to fish by covering over the eggs of trout and salmon and clogging the gills of young fry, essentially choking the fish. Debris such as plastics is harmful to wildlife and extremely unattractive, reducing the recreational value of water bodies.

3.2.4 Impact of Soil Contamination

Past industrial uses and practices have left a significant portion of Emeryville's former industrial lands contaminated to some extent. Even post-remediation, some contamination likely will remain on some of these sites, making stormwater infiltration undesirable in these cases. If allowed to infiltrate through contaminated soils, stormwater would likely leach the contamination into the water table, ultimately spreading the pollutants to the Bay. To prevent leaching from occurring on contaminated sites (and also due to Emeryville's unusually high water table), these Guidelines recommend that any stormwater treatment

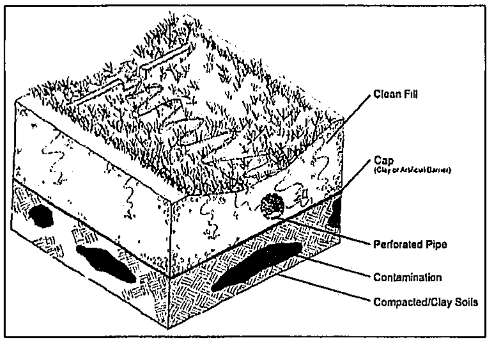


Figure 3-3: In Emeryville, soil contamination, compacted soils, clay soils, and a high water table preclude infiltration into the ground. Instead, stormwater solutions should use clean soils and be capped, lined and equipped with an under-drain system.

facility (detention, retention, bio-retention, infiltration, bio-filtration, etc.) be lined with "clean" soils and/or other media and equipped with a system of under-drains, to collect the stormwater after it is filtered and connect to the existing storm sewer system (Figure 3-2). This ensures that the stormwater receives some degree of treatment before entering the storm sewer and that it does not pick up any additional pollutants from on-site contamination. Perforated pipe should be within 2 feet of the surface.

3.3 Integrating Solutions

3.3.1 Solve Many Issues at Once

The main focus of these guidelines is stormwater quality, yet it is important to remember that dense green redevelopment offers a variety of other benefits. Chapters 5 and 6 present design solutions that, in addition to addressing stormwater runoff, promote walking and bicycling, beautify public and private development, create green space and wildlife habitat, reduce energy consumption, and have the potential to promote environmental equity. Unlike a conventional storm sewer system, which is designed to solve one problem, the green approaches presented in these

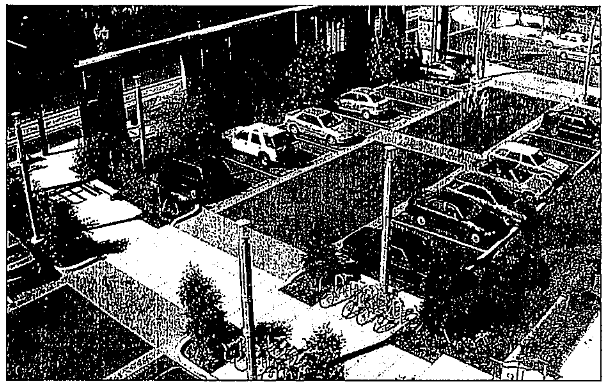


Figure 3-4: The parking lot for the EcoTrust building in Portland, OR incorporates several parking and stormwater solutions.

Guidelines serve multiple purposes and confer a range of benefits on the whole community. Therefore, these approaches should be designed and implemented with many objectives, not solely stormwater management, in mind.

3.3.2 Example Projects

As noted throughout the guidelines, parking and stormwater solutions may work best in concert with each other and with other City land use, transportation, and design policies. The following projects illustrate how multiple solutions can be applied to a site to achieve multiple goals, including, but never limited to, stormwater quality.

Ecotrust Parking Lot, Portland OR

This parking lot's bio-retention areas provide stormwater treatment and infiltration while simultaneously serving as attractive landscaping (shown in Figure 3-4). The clearly defined walkways and sidewalks, outdoor seating, and bicycle racks activate the edge of the parking lot and provide pedestrian and bicycle amenities.

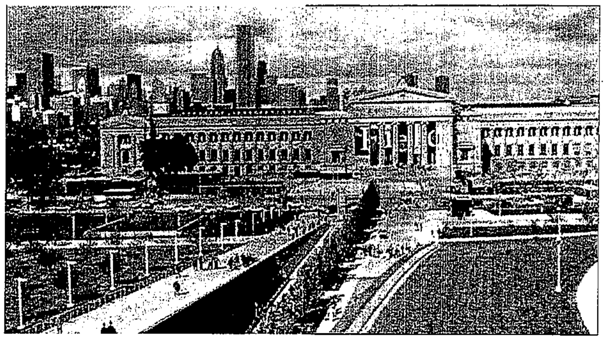


Figure 3-5: Green roof over Soldier Field parking garage, Chicago, IL

Soldier Field Green Roof Parking Structure, Chicago, IL

The intensive green roof that covers the new underground parking structure for Soldier Field provides a monumental green space in addition to reducing runoff (Figure 3-4).

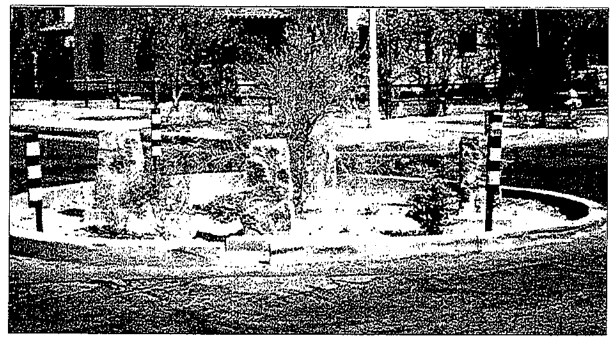


Figure 3-6: Traffic circle and infiltration basin, Arizona

Neighborhood Traffic Circle, Tucson, AZ

This infiltration basin (shown in Figure 3-5) doubles as a traffic circle, collecting stormwater off of the streets and slowing cars as they cross the intersection. This unique design feature lends character to the neighborhood while increasing pedestrian safety. In addition, it increases public awareness of stormwater as a resource by making it a visible, central design

4. DESIGNING FOR THE EMERYVILLE CONTEXT

4.1 Local Characteristics and their Design Implications

4.1.1 Emeryville's Watersheds and their Relationship to San Francisco Bay and Wetlands

The term, "watershed" (or drainage basin), refers to a land area that drains to one downstream water body (a stream, river, lake, bay or ocean). The East Bay historically contained numerous creeks and their watersheds, all of which in turn drained into San Francisco Bay. Since the mid 1800s most of these creeks have been filled or buried in underground culverts and drainage tiles. This is the case in Emeryville, where the lower reaches of two historical creeks, Derby and Temescal Creeks, were placed underground and/or channelized. The city is now drained by a system of man-made storm drains that conveys the stormwater by pipes and channels to the Bay.

The transformation of natural streambeds into underground pipes has had a substantial negative effect on both the riparian habitat (located in bands along the length of creek bed, usually 10 to 15 feet wide) and the wetland habitat (large, flat areas of marsh that occur at the terminus of the creeks, where they flow into the Bay). When intact, both of these ecosystems play important roles in the bioremediation of stormwater. The soils, plants and microorganisms in these ecosystems are capable of filtering out and breaking down many of the contaminants before they reach the Bay. Without the natural function of the riparian and wetland habitats, the water quality of the stormwater entering the Bay is seriously compromised.

4.1.2 Rainfall

The Bay Area's Mediterranean climate produces mild, dry summers and mild, wet winters. Emeryville receives an average annual rainfall of 18 inches, with roughly 70 percent (12.6 inches) falling during the wet, winter months (November through March). This annual rainfall pattern holds specific implications for water quality. The extended dry spells during the summer (sometimes more than 5 months) allow dust, pollutants, trash, and debris to accumulate on roads, parking lots, roofs, and other hard or paved surfaces. When the rains finally arrive (usually in October or November), the first several storms of the season remove the accumulated contaminants. Thus, the early rains of the season usually contain high concentrations of contaminants, resulting in very low water quality.

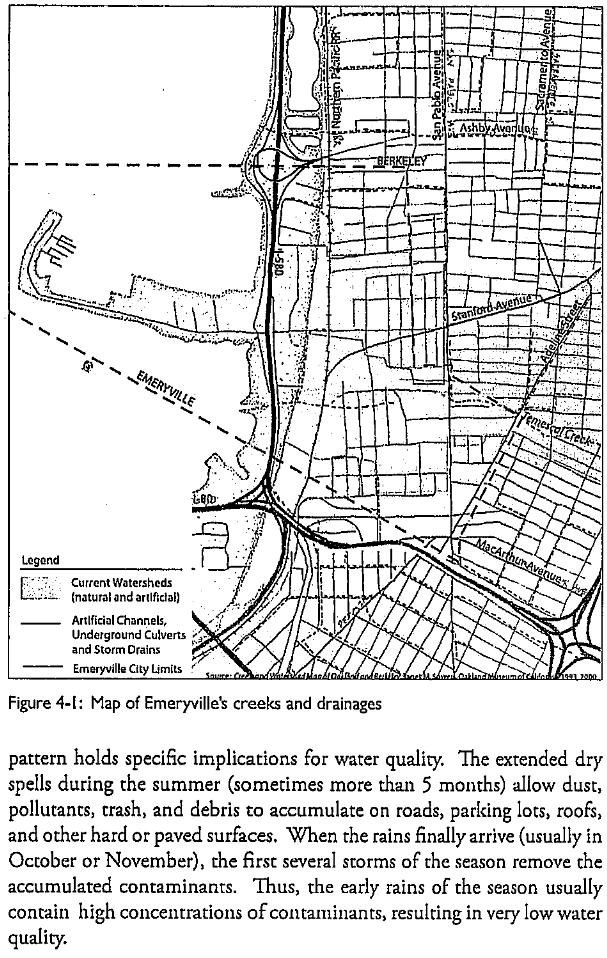


Figure 4-1: Map of Emeryville's creeks and drainages

The same conditions also hold true on a smaller time scale. Just as the first rains of the season are likely to carry the highest concentrations of contaminants, the flows from the first few minutes of any storm are likely to carry higher concentrations of pollutants than the flows from the end of the storm. This phenomenon is referred to as "first flush," where the "dirtiest" runoff comes from the beginning of a storm. Because the first few minutes of a storm can have the greatest water quality impact, many of the design solutions presented in Chapter 6 can be designed and sized to capture and treat the "first flush" rather than the runoff generated during the entire storm period.

4.1.3 Soil and Groundwater Conditions

Soil Types

Different soil types have different infiltration rates (how quickly water moves through them) based primarily on the size of the soil particles. The western part of the city has been developed on Bay mud and artificial fill; the eastern portion sits on a deposit of alluvial clay. Both Bay mud and alluvial clays are characterized by relatively small particles, which translates into relatively low infiltration rates and poor permeability. The artificial fill materials may have a coarser profile and therefore better drainage characteristics but because these materials are also likely to be contaminated (see Soil and Groundwater Contamination, below), infiltration of stormwater through this material may be inappropriate.

Soil Compaction

Because most of Emeryville is heavily urbanized, soil compaction is a common condition on sites throughout the city. Soils that have received vehicular or extensive foot traffic, construction activity, or development of any sort are likely to be compacted, even if the area has since been vacant for a long period of time. Compaction greatly reduces permeability and infiltration rates because it removes the tiny air the pockets, or voids, which create water storage capacity.

Water Table Levels

The ground water level (also referred to as the "water table") in Emeryville sits within 6 to 10 feet of the ground surface, and during the rainy season, may rise to within 2 to 4 feet of the ground surface at some locations. A high water table constrains development because it can result in flooding of underground parking and basements. Emeryville's high water table, combined with potential ground water contamination, also limits infiltration opportunities within the city.

Soil and Groundwater Contamination

In 1995, approximately 213 acres (55% of Emeryville's designated Commercial, Mixed Use and Industrial properties) were known to have soil and/ or groundwater contamination. In addition, all of the land area created from artificial landfill materials is assumed to contain contaminated debris and soils. While much of Emeryville's remaining commercial land has not been tested (and therefore it is not yet *known* whether it is contaminated) it is highly likely, based on historical land uses and hazardous materials handling practices, that the untested sites are contaminated to some degree. This has led the City and various regulatory agencies to assume that the shallow groundwater in Emeryville's commercial/industrial areas is contaminated as well.

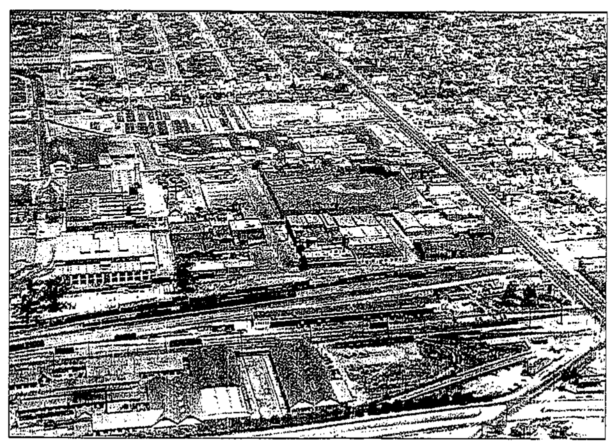


Figure 4-2: Historically, industry occupied much of Emeryville's land.

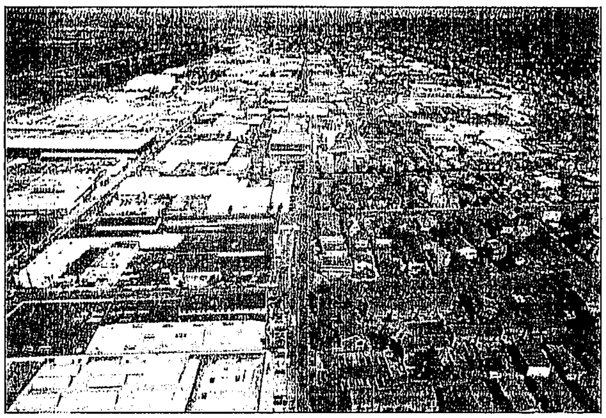


Figure 4-3: Interface between Emeryville's industrial and residential neighborhoods

4.1.4 Land Use

History of Industrial Use

From the mid 1800s through the mid 1900s, Emeryville established itself as a small but thriving industrial center. Easy access to numerous transportation routes facilitated industrial expansion in Emeryville and throughout the East Bay: railroads, shipping, and trucking provided the backbone for a variety of manufacturing companies. These industries included automobile, canning and packing plants, manufacturers of pesticides, paints, petrochemicals, and transformers, steel recycling and plating. By the middle of the 20th century, Emeryville was a major regional warehousing, transport and employment center, with 25,000 workers. The development of the East Bay freeways in the 1950s and 1960s also supported industries in Emeryville. Eventually, Emeryville ran out of developable land and began to fill in the Bay to increase areas for industry. By the 1970s, when its industrial base began to decline, Emeryville had filled 250 acres of the Bay.

Plan for Mixed-Use Redevelopment

By the 1980s, many of Emeryville's industries began to close or relocate. The city lost approximately half of its jobs, and many of the industries that closed their doors left legacies of contamination and vacant, derelict properties. In order to revitalize the community and restore the local economy, Emeryville began to re-envision itself as a mixed-use, retail, and service center. This shift in economic and employment goals required a dramatic transformation of the city's building stock and infrastructure. The emerging vision for Emeryville called for significant redevelopment projects on abandoned industrial sites but these projects could not get under way until the sites were cleaned.

In the past 15 years, many former brownfield sites in Emeryville have been successfully remediated and redeveloped as mixed-use, retail, residential, entertainment, and office developments. This process has required substantial private and public investment at the local level in addition to funding and oversight by the EPA and other state and federal agencies. Examples of Emeryville's brownfield redevelopment projects include the Emery Bay Market, the Pixar campus, the Chiron office complex, Ikea, and the Bay Street shopping center. The City plans to continue the redevelopment process with projects on the Sherwin Williams site and other, smaller infill projects throughout the city.

Many of the commercial redevelopment projects in Emeryville have included large surface parking lots. Some of the lots are also serving as impervious "caps" on contaminated sites to prevent stormwater from infiltrating through contaminated soils. The result, however, is that stormwater travels across paved surfaces, collects pollutants generated by cars, enters the stormsewer untreated and flows directly into the Bay. The next step in Emeryville's redevelopment is to incorporate innovative parking policies and programs and alternative stormwater management practices into future redevelopment projects.

4.1.5 Existing Infrastructure

Existing Roadways and Parking

Emeryville's existing street network consists of several street types: city boulevards, industrial streets, residential/buffer streets, and others. In addition, the East Shore and MacArthur freeways run through Emeryville's west and south sides.

Much of the city's paved, impervious surface can be attributed to the automobile. By reducing dependency on cars, Emeryville could find opportunities to reduce impervious surface coverage within the City on both public and private land. Less vehicular traffic would allow the narrowing of vehicle travel ways and/or the widening of the pedestrian realm of the street, which can be designed to include landscaped stormwater treatment facilities.

In addition to offering viable transportation alternatives (such as walking, biking, and transit) the City's new development should complement and support alternative transportation modes. New development should be compact, with a mix of uses, where people's everyday needs can be met without making car trips. The parking included with new residential and commercial development should also be compact.

5. INNOVATIVE PARKING SOLUTIONS

5.1 Introduction

This chapter is broken into two sections. The first section identifies innovative parking strategies to reduce and contain runoff. The second section introduces design solutions (often referred to as Best Management Practices – BMPs).

5.2 Parking Strategies to Reduce and Contain Runoff

This memorandum provides a "Toolbox" of potential parking strategies that might be considered within the City of Emeryville to guide parking provision in existing or new development. In some cases, these are strategies that are already in place in parts of the city, but could be strengthened or extended to additional neighborhoods. Others represent entirely new strategies.

All strategies focus on reducing the amount of impervious surface – and therefore environmental impact–that parking demands. This can be achieved in three ways:

- Reducing the demand for parking, meaning that fewer spaces need to be provided;
- Maximizing efficiency of parking utilization, through accommodating the same amount of demand with fewer spaces; and
- Implementing design solutions that reduce the amount of impervious surface per parking space.

5.2.1 Three Ways that Parking Strategies Improve Stormwater Quality

The following section lists several broad strategies that have been used successfully in cities and developments across the country and are appropriate for the City of Emeryville, as well.

Strategies to Reduce Demand for Parking (or match supply to demand)

Pricing Strategies

- Public Parking Pricing
- Parking Cash-out
- Unbundling Parking costs
- Parking Taxes

Transportation Demand Management (TDM) Measures

- Car-sharing
- Residential Transit Passes
- Employer TDM Programs

Changes to Parking Standards

- Parking Maximums
- Transferable Parking Entitlements
- Location- and Use-Specific Parking Standards
- Land Banking and Landscape Reserves

Strategies to Maximize Efficiency of Parking Utilization

- Strategies to encourage Shared Parking and address security and organizational barriers
- Financial Incentives
- In-Lieu Fees
- Parking Information and Guidance Systems

Strategies to Reduce Parking Surface Area for a Given Level of Supply

- Multi-level or stacked parking
- Design Controls

While all strategies bring their own distinct merits and are applicable to Emeryville, many have been implemented already and require only minor tweaking or the addition of other strategies to boost the programs. Therefore, this Toolbox concentrates on the strategies outlined in Section II: shared parking and strategies that support it. Given the current development patterns in Emeryville, these strategies, in conjunction with others in the Toolbox, have tremendous potential to maximize the efficiency of existing parking, thereby reducing impervious surface and improving the capacity for stormwater mitigation.

5.2.2 Strategies to Reduce Demand for Parking

Parking Pricing Strategies

Pricing Public Parking

Provide gates and fee collection facilities in off-street parking structures and meters on private streets.

Unbundling Parking Costs

Physically separating the cost of parking from the cost of housing or leasable space allows the buyer or tenant to choose how much parking they actually need and are willing to pay for.

Figure 5-1: City Car Share at MacArthur BART station, Oakland,CA

Transportation Demand Management Strategies

Car-Sharing

Car-sharing is a neighborhood-based, short-term vehicle rental service that makes cars available to people on a pay-per-use basis. Car-sharing dramatically reduces the need to own a vehicle, particularly a second or third car that is driven less than 10,000 miles per year.

Car-sharing services are provided in the San Francisco Bay Area by City CarShare (CCS). CCS entered the East Bay market for car-sharing over two years ago, and has several locations in Berkeley and Oakland, with pods at BART stations, residential developments and downtown locations. Developers in Emeryville could provide support for the expansion of car-sharing by incorporating car-share facilities and stations in development projects.

Car-sharing works best in dense, mixed-use neighborhoods where businesses tend to use the vehicles during the day and residents use them in the evenings and on weekends.

Residential Transit Passes

Transit passes are provided free of charge or at discounted rates to many employees in commercial developments in the Bay Area. This can be a requirement of development agreements, or implemented through voluntary TDM programs.

The same principle can also be extended to residential developments, whereby residents of a development are given free or subsidized transit passes on the local carrier (most likely AC Transit, potentially BART), in addition to access to transit and carpooling information. Or, as a cost-effective alternative, developers could contribute to Emery-Go-Round, Emeryville's local shuttle service.

At one residential development in Portland, OR, transit use increased from 30% of residents to 83% in one year after free residential transit passes were given to residents and a new light rail line opened. At a second Portland development, the program led to a 79% increase in transit use. In Boulder, CO, the residential transit pass program led to a 50% increase in transit ridership.

Figure 5-2: Residential transit passes may be used on AC Transit.

The City could reduce parking requirements for developments where residents are granted free transit passes. Alternatively, such a program could be required through development agreements.

Employer TDM Programs

Employer Transportation Demand Management Programs encompass a variety of elements to encourage employees to use alternatives to driving. Bicycle facilities might include:

- Secure parking for residents, students, and workers;
- On-street bicycle parking racks for guests;
- Showers and/or changing rooms for students and workers.

5.2.3 Maximizing Efficiency of Parking Supply

Shared Parking and Associated Strategies

Shared parking allows for the most efficient use of parking supply by serving different land uses that have different times of peak demand. For example, an office use with demand peaks during the day can share parking with restaurants, where demand is greatest during the evenings, and to some extent residential uses, where demand peaks are in the evenings, nights and on weekends. Shared parking allows the supply to be used more efficiently, since peaks in demand are smoothed out by the larger number of users.

Parking information and guidance systems

In virtually every community in the United States, there is a major gap between the perceived availability of parking, and the actual number of spaces that are available at any one time. Parking information and guidance systems help to address this gap, by directing motorists to locations where parking is available and thereby maximizing efficient use of the system.

Electronic signs, or "Real-Time Information," strategically placed at key "gateways" to a project, indicate the number of spaces available in a parking facility or section of a facility at any given moment. The same information can be provided on the web, or relayed to cellphones or personal digital assistants.

Parking information and guidance systems work best for large, centralized, publicly operated shared parking facilities. They are more difficult or expensive to implement where parking resources are spread out in smaller lots or garages, or the participation of many different or competing operators is required.

5.2.4 Strategies to reduce parking surface area for a given level of supply

Structured or Vertical Parking

An efficient way to reduce parking's contribution to stormwater runoff, if not reducing demand or traffic, is to reduce the physical amount of land devoted to parking. Vertical parking strategies, such as structured parking, parking lifts, movable parking systems, and stacked/valet parking are several such examples.

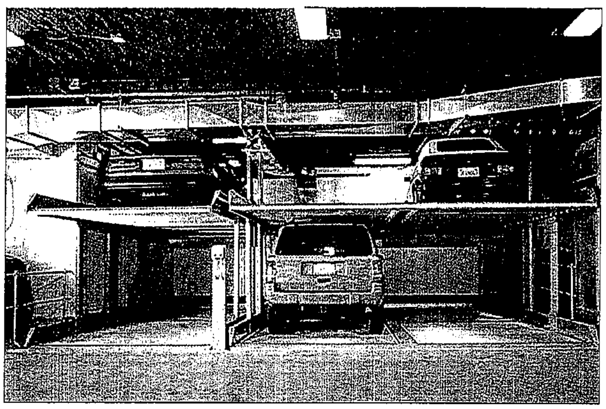


Figure 5-3: Parking lifts maximize the efficiency of parking facilities, resulting in less impervious surface area dedicated to parking.

Structured parking can be integrated with usable space in buildings that also house office or residential space, or include ground floor retail lining the street. Structured parking is an excellent way to facilitate shared parking strategies.

Parking Lifts and Valet Parking

Another effective way to "go vertical" is to provide parking lifts. These devices stack two to three cars via a mechanical lift for each surface space. They can be operated manually by residents or employees, or by a valet or parking attendant. Some tenants may be skeptical that the lifts are difficult to use or can be damaging to the car, but with the proper training on use for residents, or attendants for employer lifts, the strategy can be a practical option to double or triple the parking capacity given a set amount of land. Valet parking–where attendants park cars much closer and tighter in a given amount of parking space–can also be an effective way to maximize parking supply while minimizing impervious surface.

Structurally supported lawn can be used for peak or overflow retail parking spaces. Also, parking spaces located farthest from business entrances can be constructed on structurally supported lawn or planting areas. These types of surfaces can also be used on upper levels of garages as well as on the ground.

6. DESIGN SOLUTIONS FOR STORMWATER TREATMENT

The following sections provide detailed descriptions of potential stormwater design solutions. Due to Emeryville's unique context and variations in site-specific conditions, discussed in Chapter 4, all design solutions that involve infiltration should be equipped with under-drains connected to the storm sewer system. This measure is intended to reduce risk of groundwater contamination while allowing for stormwater treatment on site. Also, due to the increased awareness of West Nile Virus, a rare but potentially serious mosquito-borne illness, the elimination of potential mosquito breeding grounds has become a an important public health issue. To address concerns over this disease and other vector-control and public health issues associated with standing water, all of the stormwater design solutions presented in Chapter 6 should be designed and maintained to drain within 72 hours. The mosquito breeding and gestation period requires standing water conditions to persist longer than 72 hours. To reduce use of pesticides, pest resistant plants should be used.

Figure 6-1: Street trees not only provide numerous stormwater benefits but also improve the quality of the pedestrian environment.

6.1 Tree Preservation and Planting

Trees perform a variety of functions that reduce runoff volumes and improve water quality. Leaf canopies intercept and hold large quantities of rainwater on the leaf surface, preventing it from reaching the ground and becoming runoff. Root systems create voids in the soil that facilitate infiltration. Trees also absorb and transpire large quantities of ground water, making the soil less saturated, which allows more stormwater to infiltrate. Through the absorption process, trees remove pollutants from stormwater and stabilize them. Finally, tree canopies shade and cool paved areas.

The following characteristics will determine how effectively a tree performs the functions described above:

- Persistent foliage
- Canopy spread
- Longevity
- Growth rate
- Drought tolerance
- Tolerance to saturated soils
- Resistance to urban pollutants (both air and water borne)
- Tolerance to poor soils
- Root pattern and depth
- Bark texture
- Foliage texture
- Branching texture
- Canopy density

Soil volume, density, and compost, along with appropriate irrigation the first three years, are important to tree performance. Other aspects that have an influence on how street trees perform include resistance to exposure (wind, ice and heat) and resistance to disease and pest infestations.

6.1.1 New Development vs. Retrofit

During their construction phase, retrofit projects should provide protection to existing trees (including street trees) in accordance with the City's Urban Forestry Ordinance. On retrofit project sites with constrained planting space available for trees, engineered products such as root barriers and structural soils (see section 6.2 for detailed description of structural soils) can greatly increase the success rate and life span of new and existing trees.

Retrofit or new development projects with minimal constraints and no existing trees, should be planted with large trees with wide-spreading canopies. On retrofit or new development sites with overhead constraints, determine if small to medium trees and shrubs will work within the clearance. In cases where space or soil conditions are a limiting factor, small trees and shrubs may be incorporated into large containerized bio-retention gardens that receive and treat stormwater (see section 6-5 for more detail).

6.1.2 Maintenance

Most trees will generally require irrigation during their establishment period (usually up to two years after planting). Appropriate irrigation systems and watering regimes will depend on tree species and soil conditions. In addition, some species will require staking and/or pruning.

6.2 Structural Soils

Structural soils are an artificial growing medium that serve the multiple functions of encouraging root growth, satisfying pavement design and installation requirements, and increasing stormwater holding capacity.

The major challenges to tree growth within paved areas are the lack of sufficient space for tree root systems and poor soil conditions. Typically, soils located under pavement are highly compacted to meet load-bearing requirements and engineering standards. These conditions can stunt root growth, which further reduces the nutrients, oxygen and water available to the plant.

Structural soils are gap-graded gravels that consist of crushed stone, clay loam, and in some cases, a hydrogel stabilizing agent. This material can be compacted to satisfy pavement standards while still allowing roots to penetrate. The structural soil system creates a load-bearing matrix with voids filled with soil and air, essential for tree health. This allows for greater tree growth, better overall health of trees, and reduced uplifting of the pavement by tree roots. In addition, the voids that benefit the tree roots also provide increased stormwater storage capacity, allowing tree pits in paved areas to serve as a series of small detention basins.

Structural soils can add costs to a project due to additional excavation, drainage systems and the structural soil material itself. These costs are offset to some degree over the long term because of higher tree survival rates and reduced pavement maintenance costs.

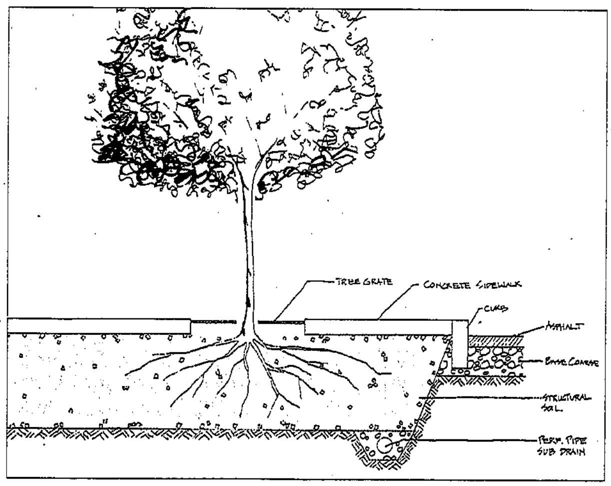
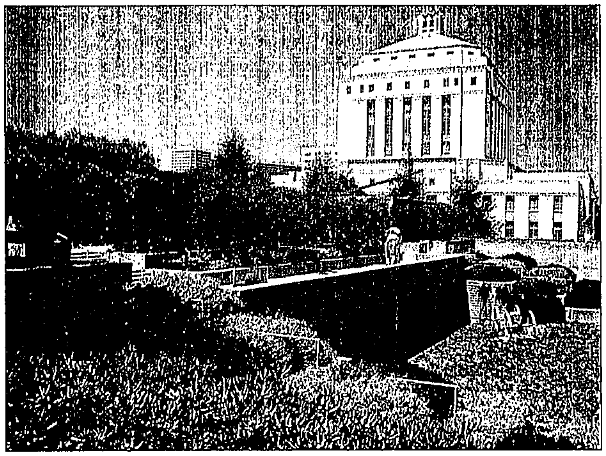


Figure 6-2: Structural soils can greatly improve the health of trees in urban settings. Their increased pore capacity is also an opportunity to retain more stormwater.



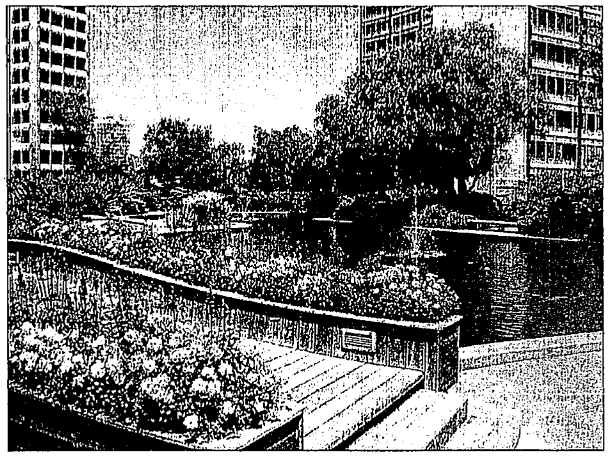
Figures 6-3: A local example of intensive green roofs include the roof-top gardens on the Oakland Museum.

6.2.1 New Development vs. Redevelopment

Structural soils can be installed at the time when trees are either first installed or replaced. Due to fact that these this process involves extensive excavation, it is easier to apply to sites that have either new construction or existing infrastructure replacement or repair.

6.3 Green Roofs

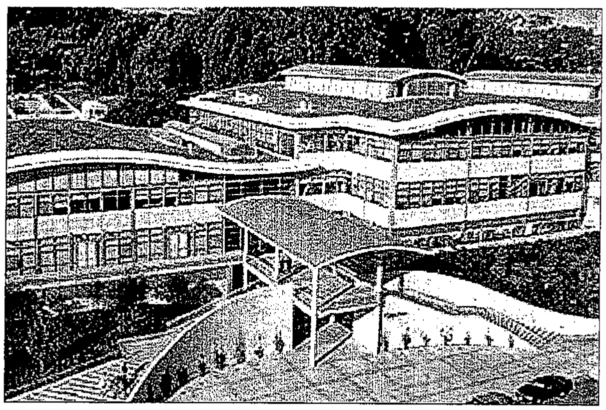
Green roofs serve a wide range of functions including stormwater runoff reduction. In urbanized areas where a large percentage of the ground is dedicated to buildings, green roofs have the potential to capture a large percentage of rainfall. By reducing the quantity of runoff that leaves a site, they attenuate peak stormwater flows, reducing frequency of sewer overflows and releases. In addition, green roofs can provide valuable green space for humans and habitat for wildlife, especially in highly urbanized areas that may otherwise lack these resources. Green roofs have also proven to reduce heating and cooling costs due to the additional insulation that they provide.

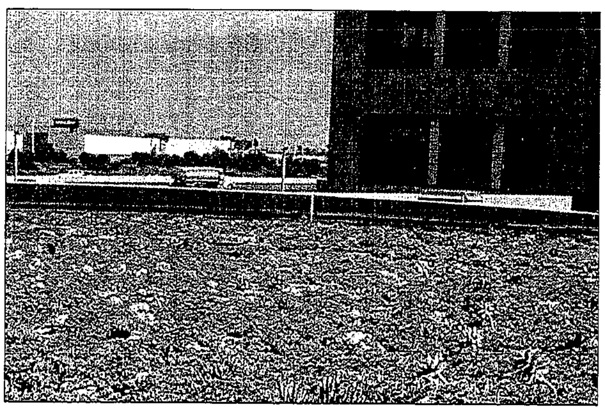


Figures 6-4: The Kaiser building, in downtown Oakland, illustrates how water storage and harvesting techniques may be used to irrigate intensive green roofs, increasing their stormwater benefit and reducing fresh water consumption.

In general, green roofs consist of a planted area integrated into the roof of a building. A green roof system requires a waterproof membrane to contain water and plant roots, a drainage system, filter cloth, a lightweight growing medium, and plants. Building air intake can be on the roof or on the sides of the building.

There are two types of green roofs: intensive and extensive. Extensive green roofs consist of a thin layer of planting medium and vegetation (6 inches or less). The planting layer can be in flats that can be lifted. These roofs usually are not intended or designed for people to access (other than construction and maintenance workers). In contrast, intensive green roofs require highly engineered structural components and much thicker layers of growing medium in order to support park-like landscapes, including trees, lawns, hardscape, etc. This type of roof can serve as a recreation space or garden area, either privately or publicly accessible. Because the two types of green roofs satisfy different goals and require different investments, the City's or developer's objectives for the green roof should determine its type and design.





Figures 6-5 and 6-6: Extensive green roofs can thrive in a Mediterranean climate. The Gap Headquarters Building, in San Bruno, CA (top) and the Ford building, in Irvine, CA (bottom).

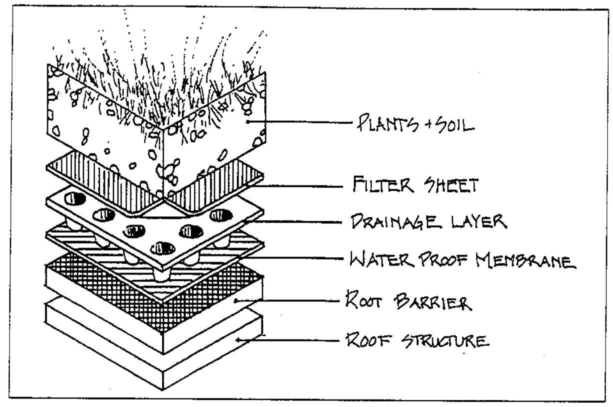


Figure 6-7: Extensive green roof technology incorporates water storage capacity and bio-retention capability.

6.3.1 New vs. Retrofit

Retrofitting an existing structure with a green roof is often (but not always) feasible. Prior to any roof retrofit project, a licensed structural engineer must determine whether the roof will be able to support the additional load. In some cases it may be possible to improve a structure by shoring up its load-bearing walls or the reinforcing the roof itself. This process can be quite expensive, however. In general, extensive green roofs are usually more suitable for retrofit situations because they have lower load and accessibility requirements than intensive green roofs.

Retrofit situations require that the roof have a small slope, rather than be totally flat. Green roofs typically work well with slopes between 5 and 20 degrees, which is steep enough to ensure proper drainage while still providing stormwater retention capacity. If the slope of the existing roof is less than 5 degrees, water will tend to pond. In order to compensate for flat roofs, the roof design may include an inclined layer of material to increase the slope. On roofs steeper than 20 degrees, a grid matrix is usually necessary to secure the growing medium and plants in place. This feature may also increase the project's cost.

6.3.2 Maintenance

Over the course of its lifetime, a green roof's maintenance demands can be minimized through proper installation and plant selection. During the first 6 months of the plant establishment period, however, maintenance is the key factor in determining the roof's success. Due to the restricted amount of growing medium and the extreme light, wind, and temperature conditions on most roofs, applying proper maintenance practices during this period is absolutely necessary to ensure that the plants fill-in and adequately cover and protect the roof's surface. Regular weeding by hand and weekly watering is usually necessary during the first 6 months after planting. Once the plants mature, maintenance schedules may include only biannual weeding, annual fertilizer application, and irrigation during droughts.

The level and type of maintenance necessary primarily depends on the types of plants selected. The plants need to be able to withstand the harsh conditions on the roof (sun, wind, temperature changes) and the shallow soil depths. Most plants on green roofs will tend to remain low-growing in these conditions but some groundcovers, such as sod, will require regular mowing and therefore should be avoided. Native succulents and wildflowers are often successful and attractive options for green roofs.

Irrigation is an important component of a green roof's maintenance. Although irrigation systems add cost, they are necessary in the short-term, during the plant establishment period, and in the long-term, in the case of droughts. Drip-line irrigation systems (embedded in the growing medium) are often an efficient means of delivering water directly to the root systems. Irrigation water for green roofs may be supplied or at least supplemented by rainwater harvesting systems.

Provided that proper construction and maintenance techniques are applied, a green roof will usually last 50 years or more. The plants, growing medium, and drainage substrate protect the roof's membrane from the elements, and the system as a whole prevents water from pooling on the roof's surface. This greatly increases the lifespan of the roof compared to conventional roofs, which usually last less than 30 years.

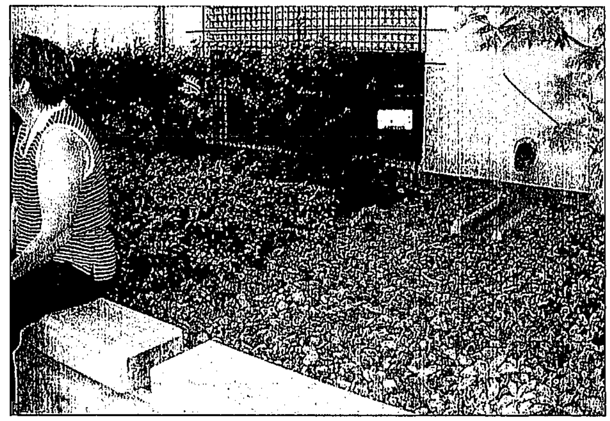


Figure 6-8: A containerized bio-retention garden provides bio-retention opportunities on constrained sites.

6.4 Bio-Retention

Bio-retention facilities are engineered stormwater solutions that mimic the natural hydrological cycle and rely on the biological and chemical processes that occur in nature to treat stormwater. Bio-retention facilities are designed to utilize soil, vegetation, hardscape elements and other materials to support and enhance the infiltration and bioremediation processes.

Bio-retention facilities include a variety of gardens and plantings (sometimes referred to as "rain gardens"), which may be planted in the ground or in containers, and artificial wetlands. Planters can be deep, treating considerable volumes of water in small areas. A bio-retention system usually consists of a splash pad to slow the velocity of runoff and a slightly depressed planting bed or container that allows shallow ponding of the stormwater (approximately 6 inches deep). The planting bed may incorporate swales, grass filter strips and/or sand filters to "pre-treat" the stormwater before it reaches the vegetation. The stored water in the bio-retention area slowly exfiltrates over a period of days into the storm sewer system or, if site conditions are favorable, into the underlying soils.

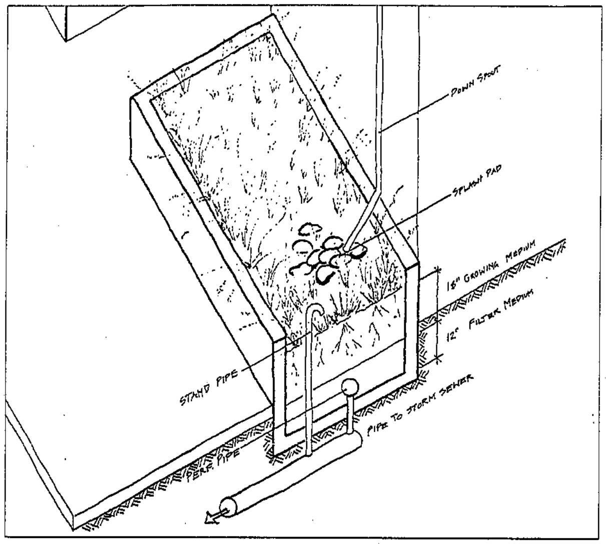


Figure 6-9: Bio-retention planters can be raised (as shown above) or at-grade to create containerized rain-gardens.

Because their basic components are water and naturalistic elements, bio-retention facilities have the potential to provide habitat and aesthetic value. Planting native plants, particularly native grasses and shrubs, can increase the effectiveness of the bio-retention facility.

The CASQA handbook refers to this solution as TC-32 Bioretention.

6.4.1 New Development vs. Retrofit

Containerized bio-retention gardens that release treated runoff into the sewer system may be appropriate on retrofit sites where space constraints, a high water table, and compacted or contaminated soils preclude the use of conventional bio-retention facilities. On these sites, planters should be designed to preserve the building's relationship to the street as much as possible.

6.4.2 Maintenance

Clogging of the bio-retention facility due to sedimentation will occur if the runoff entering the bio-retention facility contains high sediment content. Sand filters or sediment traps may be necessary to reduce the amount of sediment entering the planted area. To prevent clogging by construction debris, these facilities should be built last or runoff should be diverted around them until two months after construction is completed.

Maintenance levels greatly depend on plant selection. Although all plants will require careful maintenance and potentially irrigation during the plant establishment period, some perennial natives may require simple seasonal mowing once the plants mature.

6.5 Bio-filtration

Bio-filtration facilities include grass filter strips and vegetated swales, which filter runoff through soils and plant material to remove suspended sediments. The design solutions in this category differ from bio-retention facilities in that their primary purpose is usually to convey stormwater rather than to retain or store it. Often, bio-filtration facilities can be used to pre-treat runoff before it enters bio-retention facilities or infiltration basins/trenches, which require low sediment loads to prevent clogging. Grass filter strips are gently sloped grassy areas that are used to treat small quantities of sheet flow (0.5 inches deep) and they often are used to pre-treat runoff. Swales also rely on grassy vegetation to remove suspended sediments but, unlike filter strips, swales are channel-like and designed to accommodate a flow depth of up to 3 inches. If the underlying soil conditions preclude infiltration, the bio-filtration facility should also include an impervious liner, a pipe system to convey overflow to the storm sewer, and clean soils.

The length and slope of filter strips and swales determine their effectiveness, sizing and design. A linear swale should be approximately 200 to 250 feet in length in order to achieve an optimal 9-minute residence time. However, a swale's length can be flexible: shorter lengths can meet the minimal residence time of 5 minutes or provide effective treatment in areas with smaller discharges. A swale's longitudinal slope should be between 1 and 6 percent to allow maximum contact between water and vegetation and to prevent scouring and erosion. For slopes between 2

Figure 6-10: Swales in parking lots also buffer pedestrians from parked cars.

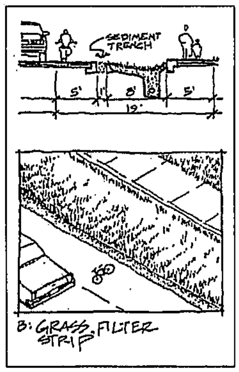


Figure 6-11: Grass filter strip

and 6 percent, features should be added to the swale to slow and spread the flow and increase residence time. Conventional check dams, curbs, trees or other landscape elements can be used to create this effect. Filter strips and swales function best when the water they treat is no more than 3 inches deep. The treatment area needs to be of adequate width to maintain these depths.

The CASQA handbook refers to these solutions as TC-10 Infiltration Trench and TC-11 Infiltration Basin.

6.5.1 New vs. Retrofit

Applications for bio-filtration in new development, redevelopment or retrofit projects in Emeryville may be limited by space constraints and soil conditions. In retrofit situations, in particular, existing underground utilities may also pose serious conflicts with bio-filtration facilities.

6.5.2 Maintenance

Maintenance plans for bio-filtration facilities should include yearly or twice yearly mowing, depending on plant types. Clippings and trimmings should usually be removed from the facility following mowing to prevent decaying material from resulting in nutrient loading. Irrigation and weeding by hand is usually necessary during the plant establishment period. Irrigation may also be necessary during drought periods, depending on plant types selected. If the infiltration facility fills with sediments, soil removal, regrading and replanting may be necessary.

6.6 Infiltration

Infiltration facilities can take a number of forms, including infiltration basins, trenches, sand filters, and French drains, all of which slow and filter runoff, thereby improving the water quality and reducing the volume of runoff leaving a site. In general, following treatment in an infiltration facility, stormwater may seep into the ground or enter a stormwater storage facility or a sewage system. However, due to Emeryville's unique context and variations in site-specific conditions, discussed in Chapter 4, all design solutions that involve infiltration should be equipped with under-drains connected to the storm sewer system. This measure is intended to reduce risk of groundwater contamination while allowing for stormwater treatment on site. It also helps to reduce flooding.

Infiltration systems often work in concert with bio-filtration facilities such as filter strips or swales, which direct stormwater from impervious surfaces into the infiltration facilities. In addition to conveying the stormwater to the infiltration facilities, swales and filter strips also treat the stormwater by removing sediments and some pollutants that could potentially clog the infiltration facility and inhibit the infiltration process.

To construct infiltration basins and trenches, the area is excavated, then back-filled with layers of coarse gravel, sand or other media to filter the runoff before it reaches the underlying soils or alternatively, a storage facility or sewer system.

Figure 6-12: This infiltration basin doubles as a traffic circle.

6.6.1 New Development vs. Redevelopment & Retrofit

Compacted soils, which are common on retrofit sites, can be problematic for infiltration systems. However, infiltration trenches and basins can be designed with larger reservoirs and some degree of exfiltration to compensate for compacted soils and/or permeable soils and under-drains can be added.

Because infiltration trenches can be both linear and narrow, they can be integrated into retrofit projects where soil and slope conditions are suitable. Existing underground utilities may complicate installation and drive up costs. Site designs for parking structures can also include infiltration facilities to collect and treat the garage's roof runoff.

6.6.2 Maintenance

Soil compaction and sedimentation, particularly during the construction phase of an infiltration system, can severely impair an infiltration facility's effectiveness. Once an infiltration facility becomes "clogged" with sediment, it can be difficult or impossible to restore. Maintenance should include regular inspections for and removal of leaf littler, trash, and debris. Installing the facility last or diverting stormwater around it until after construction can help prevent this problem.

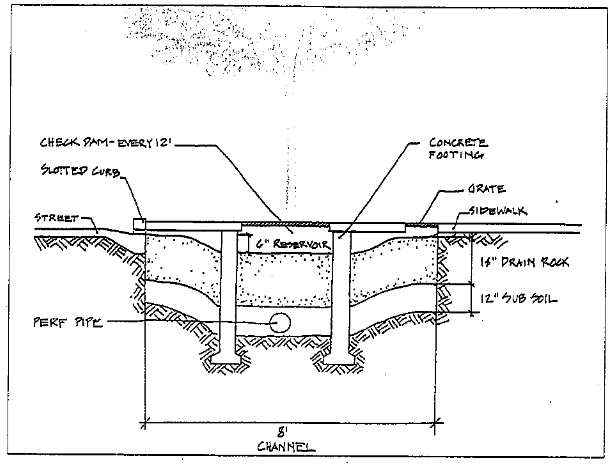


Figure 6-13: Infiltration capacity can be incorporated into the design of street tree trenches.

6.7 Permeable Paving

Permeable paving systems facilitate infiltration by allowing stormwater to soak through the voids in the pavement into an underlying basin that is filled with gravel, a layer of filter fabric, and a stone reservoir. These layers provide support for the pavement layer above and facilitate percolation into the subsoil or underdrain below. If properly installed and maintained, permeable paving can be applied to low-traffic areas such as streets, sidewalks, parking lots, recreation facilities, and pedestrian plazas to reduce runoff without limiting use or necessitating separate infiltration facilities.

The three primary types of permeable paving systems are: permeable paver block systems, pervious asphalt, and pervious concrete mixes. Permeable pavements are not suitable for all paved areas and may not be appropriate for some sites in Emeryville. Loose pavers such as cobbles should be fixed into position with a ridged edge and should comply with all applicable requirements and standards under the Americans with Disabilities Act (ADA).

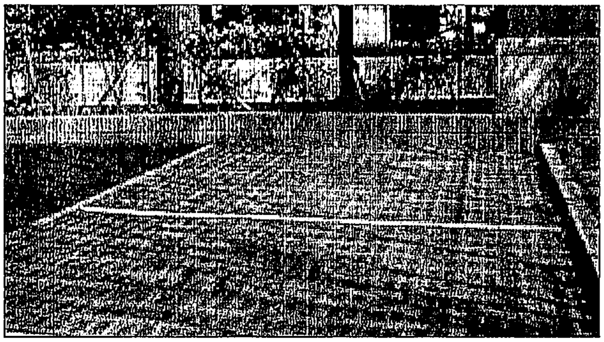


Figure 6-14: Permeable pavers may be appropriate in low traffic areas such as parking stalls.

Permeable paving materials reduce runoff and lower the temperature of runoff. Permeable pavements, particularly paver systems, can incorporate aesthetically pleasing textures and patterns. They may be ineffective in areas with high volumes of traffic, their pores are easily clogged by sediment, and without proper under-drains, they may increase the potential for groundwater contamination. Therefore, it may be necessary to combine sediment control measures with permeable pavements to minimize the sediment load. High volumes of sediments will clog the pavement and compromise its ability to infiltrate stormwater.

The CASQA handbook refers to this solution as SD-20 Pervious Pavements.

6.7.1 New Development vs. Redevelopment

In retrofit situations soils are generally compacted; thus, permeable paving systems would need a gravel subbase/stone reservoir and under-drain. Permeable pavement can easily be integrated into new construction where soil, slope and traffic conditions are suitable.

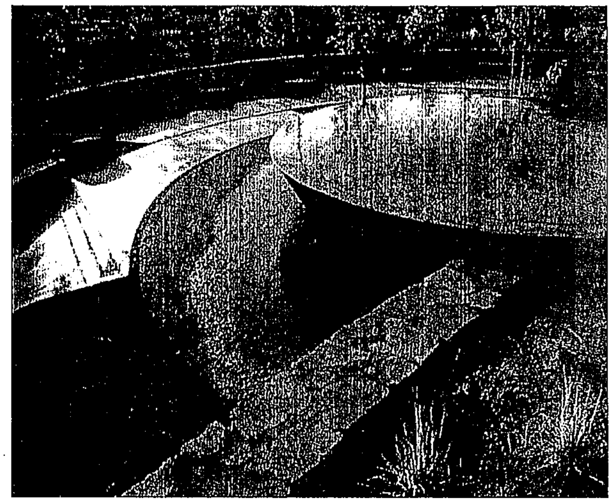
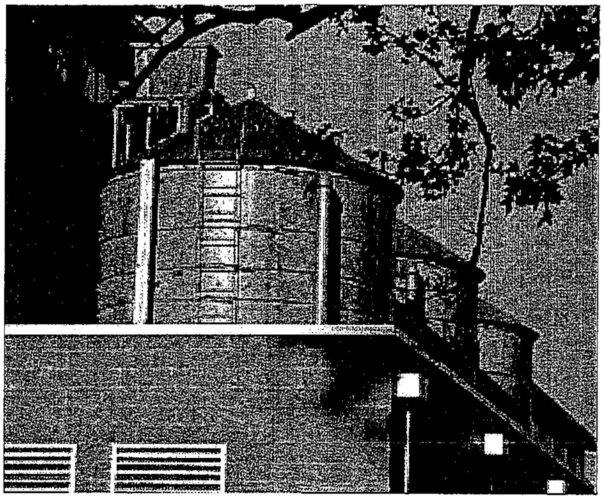


Figure 6-15: Cisterns can serve as public amenities such as the water feature pictured above.

6.8 Water Storage

Water storage systems collect rainwater from impervious building surfaces (such as roofs) and store it so it may be released soon after a storm or utilized for irrigation and other non-potable uses. This technique treats stormwater, attenuates peak runoff flows, and may conserve potable water.

Rainwater storage systems connect to a building's gutters and downspouts and convey the water to storage vessels, such as rain barrels or above- or below-ground cisterns. In "metered detention and discharge," the collected stormwater is slowly released into the landscape beds in the hours following the storm at a rate that allows for better filtration and is less taxing to the overall community storm drain. This is not necessarily an irrigation strategy, as irrigation is not required in the Bay Area during the rainy season. It is possible, however, if the water is filtered and re-



Figures 6-16: Cisterns can also be incorporated into a building's architecture.

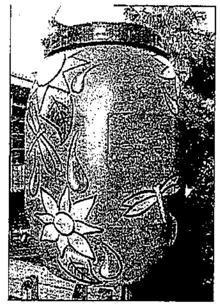


Figure 6-17: Decorated rain barrel for a residential building

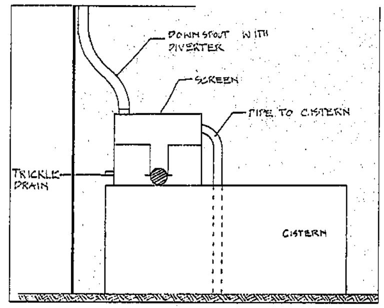


Figure 6-18: Roof washer devices separate the initial (and dirtiest) runoff and divert it away from the water storage facility.

pressurized, to distribute the collected stormwater through the irrigation system into landscape areas when other discharge points are not available. For rain water to serve as useful irrigation in the Bay Area, it would need to be stored until the dry season, requiring more storage capacity.

The CASQA handbook discusses these solutions as TC-12 Retention/Irrigation, and as cisterns and rain barrels under SD-11 Roof Runoff Controls.

Water storage systems should include preventive measures for contamination and vector control. The initial rainfall of any storm often picks up the most contamination from dust, bird droppings and other particles that accumulate between rain events on the roof surface. A roof washer device separates the dirtier, early rainfall and diverts it so that it does not mix with the cleaner runoff that follows. A roof washer will, through a simple valve design, automatically divert the first 0.02 inches of rainfall per 24 hour period per square feet of roof area away from the rainwater harvesting storage tanks or cisterns. Roof washers should be installed in such a way that they will be easily accessible for regular maintenance. Also, water storage facilities should be equipped with covers, to reduce mosquito breeding risk.

Most roofing materials are compatible with rainwater storage and harvesting systems. However, rainwater should not be collected from roofs with redwood, cedar, or treated wood shingles or shakes, which may contaminate water and soil by leaching toxic materials when wet. In addition, food-producing gardens should not be watered with rainwater from roofs with asphalt shingles.

6.8.1 New Development vs. Retrofit

Retrofitting existing buildings with above ground planters and rain barrels is usually feasible. These storage facilities can be sized to accommodate roof runoff from a major storm event provided that enough space exists between the building edge and the property line. Below ground cisterns can be more difficult and more expensive to incorporate into a retrofit project because these facilities require substantial excavation and grading, which may not be feasible due to the high water table.

Designs for new development projects can incorporate extensive water storage and harvesting measures including underground cisterns. In addition, new buildings can be designed to store water within their walls and basements.

6.8.2 Maintenance

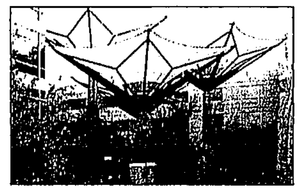
Maintenance plans for rainwater storage and harvesting facilities should include twice yearly inspections of the cisterns and rain barrels, in addition to their components and accessories, to determine if repair or replacement is necessary. Inspection and maintenance plans should cover the following items:

For Cisterns

- Roof catchment
- Gutters
- Roof washer and cleanout plug
- Cistern screen
- Cistern cover
- Cistern
- Cistern overflow pipe.
- Any accessories, such as the sediment trap, if needed

For Rain Barrels

- Roof catchment,
- Gutters and downspouts
- Entrance at rain barrel
- Rain barrel
- Runoff / overflow pipe
- Spigot
- Any accessories, such as rain diverter, soaker hose, linking kit, and additional guttering



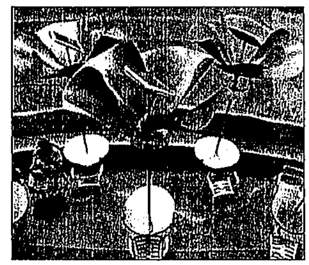


Figure 6-19 and 6-20: Rain catchers and sun shades create visual interest and provide pedestrian amenities.

6.9 Other Devices

6.9.1 Rain Catchers

In some cases, site conditions or other factors may preclude the implementation of the numerous design solutions discussed so far in this chapter. For these projects, devices such as rain catchers should be considered as an option for intercepting stormwater before it reaches contaminated pavement surfaces. These structures can collect and direct rain water into cisterns for detention, infiltration, or reuse. In addition, rain catchers are a highly visible design component and can be used to add vertical elements and visual interest to a project.

New Development vs. Retrofit

The raincatchers may be particularly useful in retrofit situations where space and soil constraints may not permit tree planting, the development of bio-retention or bio-filtration facilities or even green roofs.

6.9.2 Sun Shades

Sunshades are an example of a relatively simple intervention whose primary purpose is to increase pedestrian comfort but also provide stormwater benefits by intercepting runoff. Sunshades can also be used to mount solar cells, which provide sustainable energy.

6.10 Putting it All Together: Site Design with Design Solutions

The following description and illustrations explain how to apply the individual parking Toolbox and stormwater design solutions described in Chapters 5 and 6 at the building and site scales. The parking and design solutions are intended to be used in combination with each other and, depending on the amount of runoff and available space, will likely prove most effective for water quality when integrated with each other and dispersed throughout a site. Generally, site designers can minimize impervious surface, especially connected impervious surface; include and consolidate open space; drain paved areas toward landscaping; include vegetated courtyards; design through, landscaped interior streets with 20-foot travel ways; limit width of residential driveways serving a small number of units to 18 feet if two-way and 9 feet if one-way; use two-track driveways with permeable paving and vegetated strips; cover equipment maintenance and cleaning areas; cover trash and recycling areas; and use native or pest resistant plants

Recent development projects located in Emeryville have typically employed similar design elements, such as fire access roads, deck gardens above podium parking, street trees, and recreational open spaces. Figures 6-19 and 6-20 illustrate how stormwater design solutions can be layered onto these "typical" Emeryville design elements. For example, cisterns can collect stormwater from parking structures, roof decks can provide vegetated areas for bio-retention and rainwater harvesting. Fire access lanes can utilize porous pavements; sidewalk bio-retention basins, filled with structural soils, promote street tree growth and provided water storage capacity. Shed roofs or other moderately sloped roofs can incorporate extensive green roof technology to dramatically reduce runoff.

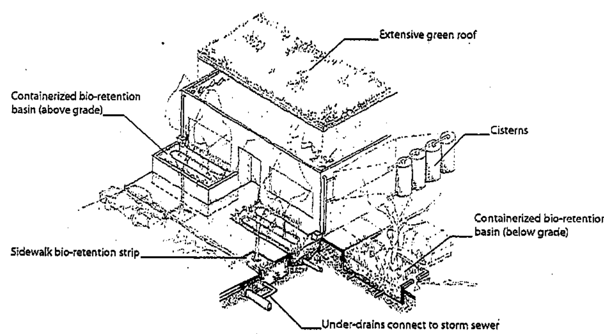


Figure 6-21: Multiple design solutions applied to the individual building scale.

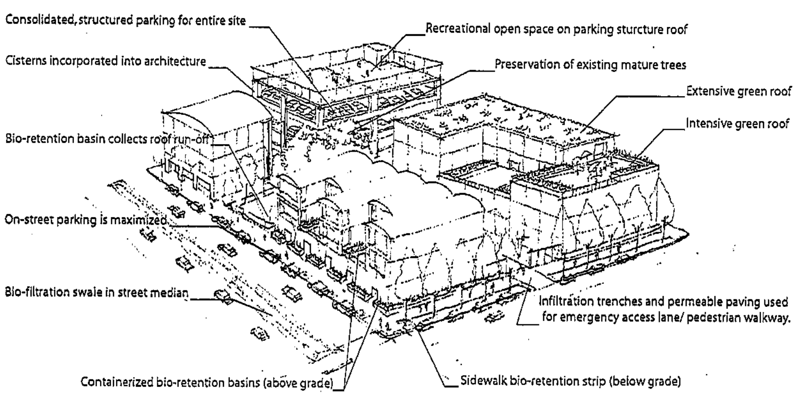


Figure 6-22: Design solutions applied to a redevelopment project at the block scale.

7. SELECTING AND SIZING STORMWATER SOLUTIONS

7.1 Overview of Design Solution Selection and Sizing Process

The following section provides guidance on effectively incorporating stormwater design solutions into the design process. The project designer can begin to consider which stormwater design solutions are most appropriate for the site and project early in the design development phase. The site design process and the selection and sizing of stormwater features are parallel processes that should overlap throughout the project's design. The selection and sizing of stormwater design solutions should not be viewed as an add-on or a band-aid applied after the fact to an otherwise completed site design. Incorporating stormwater design solutions into a development project should be viewed as an integral part of the design process - the site design should inform the stormwater design solutions and the stormwater solutions, in many respects, may inform the design of site elements. A conceptual site plan can be used to estimate a site's runoff volume. Designers appropriately select and size stormwater solutions when such data is effectively integrated with detailed site analysis including soil type and infiltration rates, slope, precipitation, soil contamination analysis, etc.

7.1.1 Site Analysis

Designers should become familiar with the conditions of the region, community, and site when selecting and sizing stormwater solutions. Collect Soil Analysis data including soil type, infiltration rates, and potential soil contamination based on historic and contemporary use. Other critical site analysis would include slope and orientation, annual average and extreme rainfall, existing vegetation or habitat zones worth incorporating into the design, and existing site stormwater flows. Where are the points on the site that receive inflowing, and discharge outflowing stormwater? What advantages do inherent site stormwater patterns yield to the overall function of the site plan and the general stormwater strategy?

7.1.2 Identify Pervious and Impervious Surfaces

Estimate what percentage of the site will be covered with roofs, parking lots, turf, hardscape, planting beds, and other surfaces. Early in the design phase the designer can begin to identify opportunities to reduce impervious areas in the site plan:

- Can parking spaces be reduced? Is a vertical parking structure possible? Can the building footprint be reduced?
- Is there an opportunity to install a green roof?
- Can turf areas be irrigated with captured rainwater? Or replaced with bio-retention gardens?
- Can pervious paving be incorporated into the paving plan?

7.1.3 Identify Appropriate Design Solutions

Once the designer has considered conditions specific to the site and community, and the pervious and impervious areas on the site plan have been established, appropriate design solutions (described in Chapter 6) can be incorporated into the site stormwater plan. Stormwater designs may be enhanced if the designer considers the following:

- Can design solutions be incorporated into site elements that are already typical for development in Emeryville such as: roof top gardens, fire access lanes, podium parking garages, etc.
- Can large shade trees be incorporated into the parking plan and in the landscape plan in general?
- Can stormwater from impervious areas on the site be directed to and filtered or infiltrated in lowered landscape beds, bio-swales, rain gardens, etc.?
- Are soils adequately protected from erosion?
- Do the landscape specifications call for a minimum of 2" of coarse mulch?
- Can rainwater from the roof be harvested and used for dry season irrigation and water features?

- Can site fixtures "rain catchers" be used to direct rainwater to catchment cisterns or ponds?
- Do the soil and planting amendment specifications prohibit synthesized chemicals and emphasize the use of compost and mulch?
- Do the maintenance specifications prohibit synthesized chemicals?

7.1.4 Siting Stormwater Design Solutions

Stormwater conveyance is ideally powered by gravity. When handling the stormwater from a parking lot or any other surface at grade it is recommended that the landscape areas and planting beds directly adjacent to the impervious surface be utilized for stormwater bio-filtration or infiltration. Street medians and parking planters are excellent candidates for bio-filtration beds. Stormwater can be directed into lowered bio-filtration beds with grading and by installing slotted curb or parking stops that allow stormwater to drain directly into landscape areas. Ideally, parking and street beds are well sized and evenly distributed throughout paved areas.

If stormwater must be conveyed from one source on the site to another zone on the property, every effort should be made to keep water flow rates slow and meandering. When stormwater is conveyed in pipes flow rates increase, filtration is negligible, and sediment and debris lead to system failure. Ideally stormwater can be conveyed in open trenches that model natural arroyos and seasonal percolation zones. The meander will help reduce flow rate, drop sediments, increase filtration, and reduce erosion. Plants and trees significantly enhance the filtration and transpiration qualities of the stormwater conveyance landscape feature. Cobble and gravel, at appropriate dimensions for flow rates, also help to improve filtration and prevent erosion.

When conveying water from a roof, however, gravity allows for stormwater to be discharged anywhere on site below the elevation of the roof gutter. Cisterns, ponds, and bio-swales therefore need not be located directly adjacent to roof sources. A closed pipe from the roof gutter will push water back up to a discharge point at the other end of the pipe at the same elevation. The key here is to allow for a drain at the low point in the pipe that is opened annually in the dry season. This drain can discharge into a simple gravel pit vault if it is subterranean.

When siting stormwater solutions, it is critical to consider the proposed site infrastructure and soil type. For instance, when the soil type is poorly drained and expansive, filtration strategies may be more appropriate than infiltration strategies in areas adjacent to infrastructure like building foundations or parking lots. Retention ponds may require lining systems when sited in well drained, large particle soil types.

7.1.5 Sizing the Design Solutions

Once the potential design solutions have been identified and located on the site, the designer is ready to calculate runoff volumes and size the stormwater design solutions accordingly. Accompanying these Guidelines is an Excel spreadsheet (available on CD or via the City's website) that calculates runoff volumes and the appropriate sizing of some of the stormwater design solutions presented in Chapter 6. The spreadsheet is intended to aid the designer during the initial stages of the design process, and can be used in two ways. First, the assumptions built into the tables can be used. The spreadsheet sizing parameters for the stormwater design solutions are consistent with the NPDES permit, which requires that development projects treat approximately 85 percent of annual rainfall, roughly equivalent to a 1-inch storm in the Bay Area. Alternatively, the designer can use the tables as a starting point, change dimensions as desired, and document those changes. Illustrations of the spreadsheet tables and a sample spreadsheet exercise are also included in this chapter.

How to use the Design Solution Sizing Spreadsheet

The process of sizing the stormwater design solutions requires at minimum a conceptual site plan. Read through the steps outlined and the example sizing exercise that follows. Identify impervious and pervious drainage areas, and select a stormwater design solution for each area. Use Tables 7-2 to 7-6 to match design solutions to drainage areas. Use Table 7-7 to "balance" design solutions and drainage areas until all drainage areas are accounted for. *Note: Blue cells indicate that the user should enter a value.*

Table 7-1: Drainage Parcels

Divide the entire site (including rooftops) in drainage parcels, each discharging into a single location.

For roof parcels, enter:

- The impervious area of roof
- The pervious area of roof garden, either intensive or extensive (extensive is typically approximately 6" of growing substrate)
- The volume of roof catchment cisterns (if applicable).

For land parcels, enter:

- The square footage of impervious area in the parcel.
- The square footage of pervious area in the parcel, using the column corresponding to the appropriate slope.

The maximum number of parcels this spreadsheet can accommodate is 9 for roof areas and 20 land areas.

Next, determine which design solution will be used for each parcel and use the appropriate spreadsheet to determine the design solution design size for each roof and land parcel.

Table 7-2: Metered Detention Design

- Enter the ID number for each parcel from Table 7-1 that will utilize Metered Detention Design in column 1. Enter roof parcel IDs in the format R1, R2, etc. in the top cells, and the site parcel IDs (in the format 1, 2, 3, etc.) in the lower cells. Do not add or remove rows. The table will automatically look up the water quality volume associated with the parcel (from Table 7-1).
- Enter the available area to receive stormwater discharge in column number 5. The table will calculate the minimum irrigation area required (assuming 0.1 in/hour soil permeability for 30 hours). The word "shortage" will appear at the end of the row if the entered area available for stormwater discharge is less than the required area.
- There is a quick calculator on this table to determine the number of gallons of stormwater an entered square footage of available landscape area can accomodate, and the reverse.

Table 7-3: Bio-Retention Basin Design

Bio-retention refers to the strategy of directing stormwater from impervious surfaces like roofs and parking lots into landscape areas specifically designed to retain, filter and sometimes infiltrate rainwater using soil, plants, bacteria and other biological means.

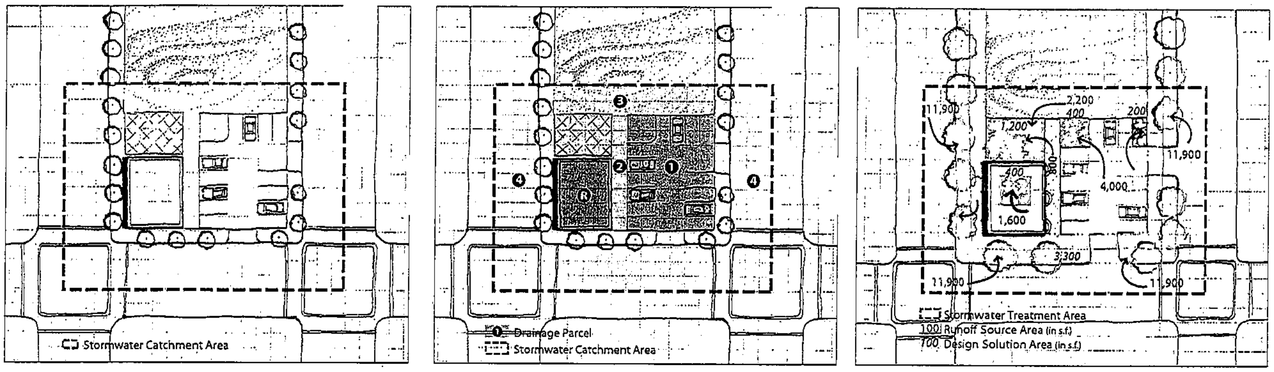
- Enter parcel ID number in column 1, as described above.
- Enter the area available to construct the bio-retention solution as width and length in columns 4 and 5, or as an area in column 6.
- The quick calculator will show the parcel area that a given bioretention area can accomodate.

Further design considerations for bio-retention are listed at the bottom of the table.

Table 7-4: Lowered Planter Strip Design

Lowered planter strips utilize the same principles as the above described bio-retention basin, however the landscape area in question is confined to the dimensions of the planter strip.

- Enter the ID number as described above.
- Enter the available length or area for a planter strip. The minimum width is set at 5' unless a new value is entered in the yellow "Enter Planter Width" box.
- Table 7-4 includes a quick calculator that tells the user how much can be treated for a given area, using the planter width as defined in the "planter width" box.
- Further design considerations are listed below the table.



Figures 7-1, 7-2, 7-3: The diagrams above illustrate the process of establishing a total drainage area for a site, dividing it into drainage parcels, calculating pervious and impervious area, and using these steps to determining runoff volumes using the worksheets provided in this section.

Table 7-5: Flow-Through Planter Box

A flow-through planter box is another form of bio-retention facility, confined to a planter box.

- Enter parcel ID number as described above.
- Enter the area of the planter box (inside dimension).
- See additional design considerations at the bottom of the spreadsheet.

Table 7-6: Bio-Filtration Swale

- Enter Parcel ID number in column 1, as described above.
- Enter the length, bottom width, side slopes and ground slope for the swale. Note: these entries must conform to the parameters indicated at the top of the column.
- Adjust design variables until:

  Design flow is equal to or less than calculated Manning's flow.

  - o Hydraulic residence time is greater than 9 minutes
  - o All design parameters fall within acceptable limits.

Table 7-7: Stormwater Balancing Sheet

If there is not enough available area to accommodate the design solution for certain parcels within the site, the user can use Table 7-7: Parcel Balancing to redistribute the parcel areas among the four volume-based design solutions (metered detention, bio-retention, lowered planter strip, and planter box). To redistribute area to a flow-based design solution (biofiltration swale), use Table 7-1 to redefine parcel areas.

This worksheet tracks the total shortage for each parcel from all four volume based design solution design spreadsheets. It also tracks the extra area available from each design solution to treat additional water quality volumes.

To balance the water quality volumes among parcels:

- The TOTAL shortage for each parcel is listed in column 4.

- The EXTRA area that other parcels can accommodate is listed in column 6. To move area from a parcel with a shortage to an adjacent area with a surplus of available area:
  - First enter the destination parcel ID number in column 5 of the parcel row with a shortage.
  - Then enter the parcel area being transferred to an alternate parcel in column number 3 of the destination parcel row.
  - Continue to redistribute the areas until the sum of all the parcel shortages (column 4) is equal to the total areas redistributed (column 3).
  - The columns are summed at the bottom of the table.

7.2 Example Sizing Exercise

The following tables and images illustrate how the spreadsheets can be applied to actual sites. Figure 7-1 depicts an example project located on a roughly 0.6-acre site (each of the grid boxes represents 100 square feet). The site is surrounded by a sidewalk and road on three sides, and the project site boundaries extend beyond the property lines to include the adjacent sidewalks and roughly half of the area of the adjacent streets. The example project consists of three impervious surfaces that will generate runoff: one commercial building, a parking lot, and pathway. The undeveloped portion of the site is a steep hillside that will also generate some runoff due to its slope. The data entered in Tables 7-1 to 7-4 correspond with the area take-offs and water quality volumes for the example site.

By following the steps outlined above, several design solutions were identified and the site has been divided into 5 drainage parcels: one roof parcels and four ground parcels. The areas for each were calculated and entered into Table 7-1. The types of design solutions that were selected for this site include: a lowered planting strip, a green roof garden with cisterns, and bio-retention gardens. These design solutions were placed in close proximity to the runoff sources and then sized using Tables 7-1, 7-2, 7-3, and 7-4 which follow this discussion.

- The runoff from the roof will be stored in cisterns and used to irrigate the roof garden. The roof garden is 400 square feet total, sufficient to accommodate stored rainwater.
- The parking lot requires 160 square feet of bio-retention area, which can be provided through a 200 sf bio-retention cell located in the parking lot.
- The path will require 32 square feet of bio-retention area, which will be provided by the raingarden located adjacent to the building. The raingarden is 1200 square feet, which leaves 1197 square feet of unused capacity.
- The hillside will require 70 square feet of bio-retention capacity. Because the raingarden has extra capacity and is located downhill and adjacent to the hillside, it can also drain to the raingarden. Once the designer decides that there is sufficient capacity in the raingarden for the path and the hillside to "share" the design solution, the two areas could be combined into one drainage area, to simplify the table.
- The sidewalk will require 476 square feet of lowered planter strip.

Note: Table 7-5, used for sizing swales, is not needed for this exercise but is included in the set of worksheets.

Figure 7-3 illustrates one of many potential site designs which treat the stormwater generated by the development entirely on site. Table 7-7, which enables the designer to quickly check the runoff "balance " for the site, indicates that not only is there adequate space for each of the design solutions, all but one has additional, surplus capacity that could be available to treat runoff from a neighboring property.

TABLE 7-1

Drainage Parcels

ROOF

ID#	ROOF Parcel Description	Impervious Area	Pervious Area (Extensive Rooftop Garden)	Total Area	Pervious Area (Intensive Rooftop Garden)[1]	Volume of Cistern Storage	Roof "C"	Water Quality Volume		Equivalent Impervious Area
		(feet^2)	(feet^2)	(feet^2)	(feet^2)	(gallons)		(feet^3)	(gallons)	(feet^2)
	C=	0.85	0.4							
R1	rooftop	1,600		2,000	400	650	0.85	0	0	1,600
R2				0			0.00	0	0	0
R3				0			0.00	0	0	0
R4				0			0.00	0	0	0
R5				0			0.00	0	0	0
R6				0			0.00	0	0	0
R7				0			0.00	0	0	0
R8				0			0.00	0	0	0
R9				0			0.00	0	0	0
		100%	85%							

[1] *Intensive rooftops (roof gardens) assumed to be self-mitigating; not included in WQ volume calc.*
[4] *Extensive rooftops (green roofs) assumed to include 6" of substrate*

TOTAL ROOF AREA 2,000

SITE

ID#	LAND Parcel Description	Impervious Area	Pervious Area[2,3]			Total		Parcel "C"	Water Quality Volume		Equivalent Impervious Area
			Flat	Average	Steep						
		(feet^2)	(feet^2)	(feet^2)	(feet^2)	(feet^2)	(acres)		(feet^3)	(gallons)	(feet^2)
	C=	0.85	0.25	0.33	0.37						
1	parking	4,000				4,000	0.09	0.85	217	1,626	4,000
2	path	800				800	0.02	0.85	43	325	800
3	slope				2,200	2,200	0.05	0.37	51	384	1,760
4	streets and sidewalks	11,900				11,900	0.27	0.85	647	4,837	11,900
5						0	0.00	0.00	0	0	0
6						0	0.00	0.00	0	0	0
7						0	0.00	0.00	0	0	0
8						0	0.00	0.00	0	0	0
9						0	0.00	0.00	0	0	0
10						0	0.00	0.00	0	0	0
11						0	0.00	0.00	0	0	0
12						0	0.00	0.00	0	0	0
13						0	0.00	0.00	0	0	0
14						0	0.00	0.00	0	0	0
15						0	0.00	0.00	0	0	0
16						0	0.00	0.00	0	0	0
17						0	0.00	0.00	0	0	0
18						0	0.00	0.00	0	0	0
19						0	0.00	0.00	0	0	0
20						0	0.00	0.00	0	0	0
		100%	70%	75%	80%						

TOTAL SITE/ROOF AREA 20,900 sq.feet

NOTES

[2]

Pervious Area	Ground Slope
Flat	2% or Less
Average	2%-7%
Steep	Greater than 7%

Assuming Fair Condition of Pervious Surface (Grass cover on 50%-75% of total Area)
Source:Chow V., Maidment, D., Mays, L., Applied Hydrology, McGRaw-Hill, Inc., 1988

[3] Pervious Areas includes grassy areas, areas paved with pervious pavers/pavement as well as other pervious surfaces (ie gravel, vegetated, etc.)
Equivalent impervious area is a percentage of pervious area (70-80% depending on slope)

Resources:

General References:
http://www.santosaca.gov/planning/stormwater/index.htm#6
(this site includes several links to other stormwater treatment resources on the web)
http://www.stormwatercenter.net/
(click on "Assorted Fact Sheets" link, and then browse the fact sheets on different Stormwater BMPs

California Stormwater Best Management Practice Handbook, January 2003
Camp Dresser & McKee, et al., California Stormwater Quality Association: Stormwater Best Management Pract online at:
http://www.cabmphandbooks.com/Development.asp
(note, if above link will not open, go to : www.cabmphandbooks.com, and click on the picture link entitled "New

Portland Stormwater Management Manual, revision #3, September 2004
http://www.portlandonline.com/bes/index.cfm?c=35122

Hydrology Reference
Chow V., Maidment, D., Mays, L., Applied Hydrology, McGRaw-Hill, Inc., 1988

Greenroofs run-off coefficients
http://www.biw.kuleuven.be/lbh/lbnl/ecology/pdf-files/pdf-art/jeroen/procgreenroofs.pdf

TABLE 7-2

Metered Detention Design

Enter: Parcel ID (R1–9 for roofs, 1–20 for Land Parcels) and site area available for irrigation with stormwater

1	2		4	5				
Parcel ID#	WQ Volume to be Stored (from Table1)	Equivalent Impervious Area	Minimum Irrigation Area Required	Irrigation Area Available On-Site		Facility Area Shortfall	Surplus Facility Area	Treatment Capacity (Contributing Area)*
ROOF	*(feet^3)*	*(feet^2)*	*(feet^2)*	*(feet^2)*		*(ft^2)*	*(ft^2)*	*(ft^2)*
r1	87	1600	348	400	OK	0	52	1,839
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
LAND AREA								
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0
	0	0	0		OK	0	0	0

* Treatment Capacity is the contributing pervious area (or equivalent

Quick Calculator

Enter Available Area for Irrigation:	400	sq. ft
You can use: 100 feet^3 OR	748	gallons
Enter gallons of cistern storage:		gallons
You need irrigation area of:	0	sq ft

A008538

TABLE 7-3
Bioretention Basin Design

Enter: Parcel ID (R1-9 for roofs, 1-20 for Land Parcels) and available width and length -OR- area (square feet) available to construct the facility

1	2	3	4	5	6	7	8	9	10	11
Parcel ID#	Equivalent Impervious Area	Minimum Required Facility Area	Available Width (5ft min)	Available Length	-OR- enter available area	Available Area		Facility Area Shortfall	Surplus Facility Area	Treatment Capacity (Contributing Area)
ROOF	*(feet^2)*	*(feet^2)*	*(feet)*	*(feet)*	*(feet^2)*	*(feet^2)*		*(ft^2)*	*(ft^2)*	*(ft^2)*
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
LAND AREA										
1	4,000	160	5	0	200	200	OK	0	40	5,000
2	800	32	5	0	32	32	OK	0	0	800
3	1,760	70	5	0	1,197	1,197	OK	0	1,127	29,925
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0
	0	0	5	0		0	OK	0	0	0

Quick Calculator

Enter area of Bioretention facility ______ square feet

You can treat runoff from: 0 square feet *of impervious (or equivalent imp.) area*

- Minimum facility width is 5' (using parameters below)
- Minimum bottom width is 3'
- Line facility with at least 12" topsoil with minimum 5"/hour infiltration rate
- Maximum side slope is 2:1'
- Maximum ponding depth is 18"; minimum 6"
- Underdrains recommended due to high water table
- Provide overflow outlet to storm drain
- Do not install in locations with frequent pedestrian traffic
- Plant and irrigate

TABLE 7-4

Lowered Planter Strip Design *(Linear Feature)*

Enter: Parcel ID (R1-9 for roofs, 1-20 for Land Parcels) and available width and length -OR- area (square feet) available to construct the facility

1	2	3	4	5	6	7	8	9	10	11
Parcel ID#	Equivalent Impervious Area	Minimum Required Facility Area	Available Width (5ft min)	Available Length	-OR- enter available area	Available Area		Facility Area Shortfall	Surplus Facility Area	Treatment Capacity (Contributing Area)
ROOF	*(feet^2)*	*(feet^2)*	*(feet)*	*(feet)*	*(feet^2)*	*(feet^2)*		*(ft^2)*	*(ft^2)*	*(ft^2)*
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
LAND AREA										
4	11,900	476	8	330		2,640	OK	0	2,164	66,000
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0
	0	0	5			0	OK	0	0	0

Quick Calculator

Enter area of lowered planter strip [ ] square feet

You can treat runoff from:
0 square feet
of impervious (or equivalent imp.) area

- Minimum facility width is 5' (using parameters below)
- Minimum bottom width is 3'
- Line facility with at least 12" topsoil with minimum 5"/hour infiltration rate
- Maximum side slope is 2:1'
- Maximum ponding depth is 18"; minimum 6"
- Underdrains recommended due to high water table
- Provide overflow outlet to storm drain
- Do not install in locations with frequent pedestrian traffic
- Plant and irrigate

TABLE 7-5

Flow-Through Planter Box Design *(Linear Feature)*

Enter: Parcel ID (R1-9 for roofs, 1-20 for Land Parcels), Design planter area (interior dimension)

1	2	4	6	7	8	9	10
Parcel ID#	Equivalent Impervious Area	Minimum Required Facility Area	Available Area on Site		Facility Area Shortfall	Surplus Facility Area	Treatment Capacity (Contributing Area)
ROOF	*(feet^2)*	*(feet^2)*	*(feet^2)*		*(ft^2)*	*(ft^2)*	*(ft^2)*
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
LAND AREA							
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0
	0	0		OK	0	0	0

Quick Calculator

[ ] square feet

Enter area (interior dimension) of planter box

You can treat runoff from:

0 square feet

of impervious (or equivalent imp.) area

- Minimum planter box width is 18" (inside dimension)
- Minimum depth is 40" (between overflow and underdrain as outlined below)
- Underdrain and overflow outlet required
- Allow for 8" of ponding above topsoil
- 18" topsoil with minimum 5"/hour infiltration rate required
- Pea gravel layer beneath topsoil (12" recommended)
- Plant and irrigate

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TABLE 7-6
Biofiltration Swale Design

Enter Parcel ID; enter facility design variables; check design flow<Mannings flow (column 6); check residence time >9 min (column 9)

1	2	3	4	5	6	7	8	9	10	11	12	13
Site Specific Information							Design Variables					
Parcel ID#	Parcel Area		Parcel "C" Value	Intensity	Design Flow	Manning's Flow (calculated)	Length	Bottom Width	Side Slopes	Ground Slope	Hydraulic residence time	Swale Area
	(feet^2)	(acres)		(inches/hour)	(feet^3/sec)	(feet^3/sec)	(feet)	(feet)	(H:V)	(feet/feet)	(minutes)	(feet^2)
					(<Mannings Flow)		(MIN 100')	(2'-10')	(>3)	(0.01-0.025)	(MIN 9 minutes)	(depth = 1')
ROOF												
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
LAND AREA												
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0
	0	0.00	0.00	0.20	0.00	0.00					0.00	0

TABLE 7-7
Parcel Balancing (Volume Based)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
						TREATMENT AREA SHORTAGE					SURPLUS TREATMENT AREA			
Roof Parcels	Initial Treatment Area Requirement (feet^2)	Treatment Area from Adjacent Parcels (feet^2)	TOTAL SHORTAGE (feet^2)	PARCEL SHORTAGE MOVED TO parcel ID	AVAILABLE EXCESS (feet^2)	Metered Detention (ft^2)	Infiltration/ Bioretention (ft^2)	Flow-Through Planter Box (ft^2)	Lowered Planter Strip (ft^2)		Metered Detention (ft^2)	Bio-retention (ft^2)	Flow-Through Planter Box (ft^2)	Lowered Planter Strip (ft^2)
						8	9	8	9		9	10	9	10
Roof Area														
R1	0		0		52	0	0	0	0		52	0	0	0
R2	0		0		0	0	0	0	0		0	0	0	0
R3	0		0		0	0	0	0	0		0	0	0	0
R4	0		0		0	0	0	0	0		0	0	0	0
R5	0		0		0	0	0	0	0		0	0	0	0
R6	0		0		0	0	0	0	0		0	0	0	0
R7	0		0		0	0	0	0	0		0	0	0	0
R8	0		0		0	0	0	0	0		0	0	0	0
R9	0		0		0	0	0	0	0		0	0	0	0
Land Area														
1	0		0		40	0	0	0	0		0	40	0	0
2	0		0		0	0	0	0	0		0	0	0	0
3	0		0		1,127	0	0	0	0		0	1,127	0	0
4	0		0		2,164	0	0	0	0		0	0	0	2,164
5	0		0		0	0	0	0	0		0	0	0	0
6	0		0		0	0	0	0	0		0	0	0	0
7	0		0		0	0	0	0	0		0	0	0	0
8	0		0		0	0	0	0	0		0	0	0	0
9	0		0		0	0	0	0	0		0	0	0	0
10	0		0		0	0	0	0	0		0	0	0	0
11	0		0		0	0	0	0	0		0	0	0	0
12	0		0		0	0	0	0	0		0	0	0	0
13	0		0		0	0	0	0	0		0	0	0	0
14	0		0		0	0	0	0	0		0	0	0	0
15	0		0		0	0	0	0	0		0	0	0	0
16	0		0		0	0	0	0	0		0	0	0	0
17	0		0		0	0	0	0	0		0	0	0	0
18	0		0		0	0	0	0	0		0	0	0	0
19	0		0		0	0	0	0	0		0	0	0	0
20	0		0		0	0	0	0	0		0	0	0	0
	TOTAL	0	0		3,383	CHECK TOTALS -- Column 3 should be equal to or greater than 4, and less than 6								

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8. CASE STUDIES

8.1 Buckman Heights and Buckman Terrace, Portland, OR

Location: 430 and 303 NE 16th Avenue, Portland, OR

Summary: These two projects represent an example of green, mixed use and mixed income developments. The buildings have been widely recognized locally and nationally, particularly for their transportation/ land use strategies and stormwater management techniques.

Site Area: 2.8 acres

Units: 274

Density: 72 units per acre and 152 units per acre

Parking: 128

Design: Murase

Developer: Prendergast & Assoc.

Owner: Prendergast & Assoc.

General Contractor: Walsh Construction

Date Completed: 1998, 2000

Stormwater Benefits: Stormwater infrastructure includes: landscape infiltration, landscaped swales, permeable surfaces, stormwater planters, a 2,000 square foot green roof, and a back-up dry well. Native plants in landscaped areas reduce the need for irrigation. Rain sensors in irrigation system shut off irrigation when it isn't needed.

Parking Strategies: Bicycle facilities provide incentives not to use a car. Included in the facilities are the following: secure indoor bike storage for 90 bikes, a loaner bike, a bike repair work stand, tire pump, lockers, and the presence of bike lanes in the surrounding area. Another alternative to owning a car (and parking it) is the car sharing program offered by the development. When residents cannot get somewhere via the four high-frequency bus lines, light rail, bike lanes or pedestrian routes, they can call and reserve a car, enter a code to access it in the garage, and return it when finished (trip data is sent wirelessly to the service provider). The parking that is offered at the apartments is mostly under-building parking to reduce impervious surface coverage.

8.2 The Crossings, Mountain View, CA

Location: 2255 Showers Drive, Mountain View, CA

Summary: The Crossings is a mixed use, transit- and pedestrian-oriented community. The neighborhood provides a range of housing and retail opportunities, including single-family homes, townhouses, rowhouses, apartments, and retail. The narrow (27-foot wide) tree-lined streets allow for connectivity through a grid pattern, thus creating a walkable neighborhood with several small parks and playgrounds. Demand for housing in the Crossings has been high and the units have sold and re-sold quickly.

Site Area: 18 acres

Units: 397

Density: 22 units per acre

Parking: unknown

Design: Calthorpe Associates

Developer: TPG Development

Owner: Plymouth Group

General Contractor: unknown

Date Completed: 1999

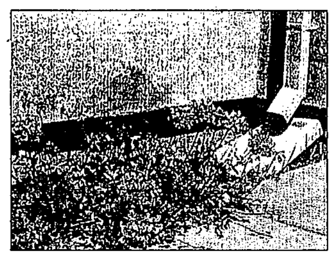

Figure 8-1: Disconnected downspouts drain to planted bio-filtration strips.

Stormwater Benefits: Transportation-related pollutant reduction, disconnected downspouts drain into landscaping, turf block fire lanes, landscaped center of driving circles, reduced impervious surface area, reduced velocity of runoff, and reduced directly-connected impervious surface area (DCIA).

Parking Strategies: All parking for the apartments is located underneath the building footprint; the rowhouses have first floor garages; the close proximity of transit and neighborhood retail decreases parking demand at walker and rider destinations. According to a 2001 Caltrain survey, over 60% of all passengers access the Crossings-San Antonio Caltrain Station by walking or biking.

8.3 Agilent, Palo Alto, CA

Location: 395 Page Mill Road, Palo Alto, CA

Summary: The corporate headquarters facility for Agilent Technologies in Palo Alto, California employs numerous green stormwater features and promotes alternative forms of transportation to reduce parking demand. According to Agilent maintenance staff, the efforts and costs of maintenance are comparable to that for typical landscaping. In addition to their environmental benefits, features like the detention basin provide visual amenities for employees and a visual buffer for the neighboring residential community.

Site Area: 10 acres

Total SF: 215,000

Density: 0.49 FAR

Parking: unknown

Design: DES Architects

Developer: unknown

Owner: Agilent

General Contractor: unknown

Date Completed: unknown

Figure 8-2: A cobble "swale" at Agilent

Stormwater Benefits: A detention basin with native vegetation along banks, a parking lot with vegetated swales, roof downspouts draining to landscaping, it promotes alternative transportation by providing bike racks and lockers, an onsite bus stop, and carpool/vanpool parking, and it has a two level structure parking that drains to a rock filter bed.

Parking Strategies: Agilent's strategy to reduce parking demand focuses on the promotion of alternative transportation. The company provides bike racks and showers to encourage employees to bike to work, and additional bike lockers and a bus stop are located at the Page Mill Road entrance. Agilent also encourages employees to carpool by providing designated car/van pool areas.

8.4 Google, Mountain View, CA

Location: 1600 Amphitheatre Parkway, Mountain View

Summary: This public/private venture with the City of Mountain View resulted in 500,000 square feet of research and development and administrative space for Google's corporate headquarters. The entire ground level of the complex, including landscaped areas, is built above an underground parking lot

Site Area: 29.5 acres

Total SF: 500,000

Density: 0.53 FAR

Parking: 1,735

Design: Studios Architecture

Developer: unknown

Owner: Google

General Contractor: Devcon

Date Completed: 2004

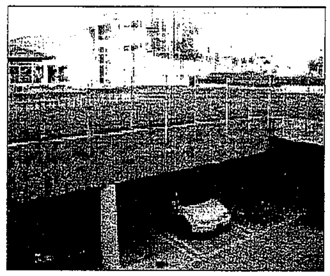

Figure 8-3: Google's green roof deck over parking.

Stormwater Benefits: Green roof, permeable paving, native vegetation, natural treatment of runoff, transportation related pollution reduction, reduced velocity of runoff, and reduced impervious surface area.

Parking Strategies: Underground parking lot and bike racks to promote bicycle commuting.

9. APPENDICES

Glossary of Terms

Base Flow – The portion of stream flow that is not runoff and results from seepage of water from the ground into a channel over time. The primary source of running water in a stream during dry weather.

Best Management Practice (BMP), nonstructural – Strategies implemented to control stormwater runoff that focus on pollution prevention, such as alternative site design, education, and good housekeeping measures.

Best Management Practice (BMP), structural – Engineered devices implemented to control, treat, or prevent stormwater runoff.

Bio-filtration – The use of vegetation such as grasses and wetland plants to filter and treat stormwater runoff as it is conveyed through an open channel or swale, or collects in an infiltration basin (see Bio-retention).

Biological Diversity – The concept of multiple species or organisms living together in balance with their environment and each other.

Bio-retention – The use of vegetation in retention areas designed to allow infiltration of runoff into the ground. The plants provide additional pollutant removal and filtering functions.

Detention - The storage and slow release of stormwater following a precipitation event by means of an excavated pond, enclosed depression, or tank. Detention is used for both pollutant removal, stormwater storage, and peak flow reduction. Both wet and dry detention methods can be applied.

Evapotranspiration - The loss of water to the atmosphere through the combined processes of evaporation and transpiration, the process by which plants release water they have absorbed into the atmosphere.

Filter Strip - Grassed strips situated along roads or parking areas that remove pollutants from runoff as it passes through, allowing some infiltration, and reductions of velocity.

Floodplain - Can be either a natural feature or statistically derived area adjacent to a stream or river where water from the stream or river overflows its banks at some frequency during extreme storm events.

Green Roof - A contained space over a building that is covered, partially or entirely, with living plants.

Groundwater - Water that flows below the ground surface through saturated soil, glacial deposits, or rock.

Hydrology - The science addressing the properties, distribution, and circulation of water across the landscape, through the ground, and in the atmosphere.

Impervious surface - A surface that cannot be penetrated by water such as pavement, rock, or a rooftop and thereby prevents infiltration and generates runoff.

Imperviousness - The percentage of impervious cover within a defined area.

Infiltration - The process or rate at which water percolates from the land surface into the ground. Infiltration is also a general category of BMP designed to collect runoff and allow it to flow through the ground for treatment.

Metered Detention and Discharge - A system where stormwater is collected in a cistern pond and then slowly released into the landscape beds or the storm drain in the following hours at the rate that allows for better filtration and is less taxing to the overall community storm drain.

National Pollutant Discharge Elimination System (NPDES) - A provision of the Clean Water Act that prohibits discharge of pollutants into waters of the United States unless a special permit is issued by the EPA, a state, or (where delegated) a tribal government or and Indian reservation.

Outfall - The point of discharge from a river, pipe, drain, etc. to a receiving body of water.

Peak discharge - The greatest volume of stream flow occurring during a storm event.

Polluted runoff - Rainwater or snowmelt that picks up pollutants and sediments as it runs off roads, highways, parking lots, lawns, agricultural lands, logging areas, mining sites, septic systems, and other land-use activities that can generate pollutants.

Porous pavement and pavers - Alternatives to conventional asphalt that utilize a variety of porous media, often supported by a structural matrix, concrete grid, or modular pavement, which allow water to percolate though to a sub-base for gradual infiltration.

Retrofit - The creation or modification of a stormwater management practice, usually in a developed area, that improves or combines treatment with existing stormwater infrastructure.

Runoff - Water from rainfall, snowmelt, or otherwise discharged that flows across the ground surface instead of infiltrating the ground.

Sanitary sewer system - Underground pipes that carry only domestic or industrial wastewater to a sewage treatment plant or receiving water.

Sedimentation - A solid-liquid separation process utilizing gravitational settling to remove soil or rock particles from the water column.

Siltation - A solid-liquid separation process utilizing gravitational settling to remove fine-grained soil or rock particles from the water column.

Storm sewer system - A system of pipes and channels that carry stormwater runoff from the surfaces of building, paved surfaces, and the land to discharge areas.

Stormwater - Water derived from a storm event or conveyed through a storm sewer system.

Surface water - Water that flows across the land surface, in channels, or is contained in depressions on the land surface (e.g. runoff, ponds, lakes, rivers, and streams).

Swale - A natural or human-made open depression or wide, shallow ditch that intermittently contains or conveys runoff. Swales can be equipped with an underdrain or other man-made drainage device. and can be used as a BMP to detain and filter runoff.

Urban runoff - Runoff derived from urban or suburban land-uses that is distinguished from agricultural or industrial runoff sources.

Water (hydrologic) cycle - The flow and distribution of water from the sky, to the Earth's surface, through various routes on or in the Earth, and back to the atmosphere. The main components are precipitation, infiltration, surface runoff, evapotranspiration, channel and depression storage, and groundwater.

Water table – The level underground below which the ground is wholly saturated with water.

Watershed - The land area, or catchment, that contributes water to a specific waterbody. All the rain or snow that falls within this area flows to the waterbodies as surface runoff, in tributary streams, or as groundwater.

Acronyms

BMP - Best Management Practice

CCS - City Car Share

CEQA - California Environmental Quality Act

EPA - United States Environmental Protection Agency

MS4 - Municipal Separate Storm Sewer System

NEPA - National Enviornmental Policy Act

NPDES - National Pollutant Discharge Elimination System

NRDC - Natural Resources Defense Council

TDM - Transportation Demand Management

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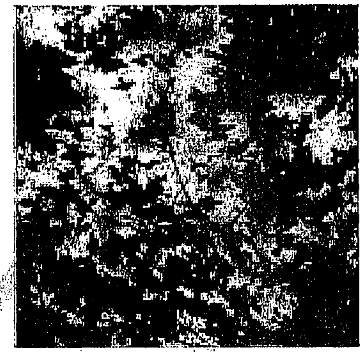

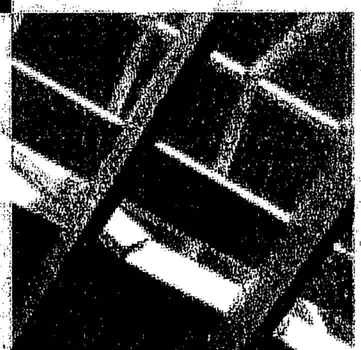
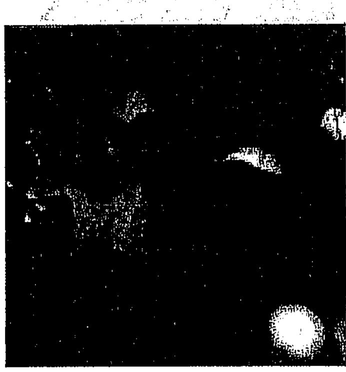


GUIDELINES

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DISCLAIMER

This publication contains guidance for builders engaged in or interested in green building products and practices for residential design, development and construction. This publication is not intended to be exhaustive and all-inclusive and the enclosed guidelines are not to be considered the only method of green building. These guidelines for green building originate from the collective experience of leading personnel in the green building movement (marketplace), but must, due to the nature of the responsibilities involved, be presented only as a guide for the use of a qualified developer, builder, remodeler, or design professional.

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INTRODUCTION

The process of green building is to incorporate environmental considerations into every phase of the home building process. That means that during the design, construction, and operation of a home, energy and water efficiency, lot development, resource efficient building design and materials, indoor environmental quality, homeowner maintenance, and the home's overall impact on the environment are all taken into account.

Now to answer the question, "Why should we care about green building?" There are many compelling reasons for changing the way in which we build and operate homes. Although we cannot avoid impacting the environment when we build a house, green building can work toward minimizing that environmental impact.

These guidelines were designed with the mainstream home builder in mind. We recognize that many home building companies already incorporate some elements of green building into their current practices. However, the purpose of these guidelines is to highlight ways in which a mainstream home builder can effectively weave environmental concerns holistically into a new home and to provide a tool that local associations can use to create a green home building program.

At the time these guidelines were created, there were 28 green home building programs in operation throughout the United States. These programs have done a great job at spreading the word about green home building. However, there are numerous other locales that are interested in green home building that do not have the resources but have not had the resources to create a program from scratch. These guidelines are intended to serve as a toolkit for home builder associations to create new programs, and to help those programs expand and flourish.

Guiding Principles

As noted above, during the process of building a green home, a builder takes numerous considerations into account simultaneously and consciously incorporates environmental issues into all decisions. The attached model green home building guidelines consist of a variety of distinct line items that a builder can choose from in creating a green home. For organizational purposes, we have grouped the line items into overarching sections, or guiding principles. Below are the guiding principles addressed in green home building:

Guiding Principle – Lot design, preparation, and development

Resource efficient site design and development practices help reduce the environmental impacts and improve the energy performance of new housing. For instance, site design principles such as saving trees, constructing onsite storm water retention/infiltration features, and orienting houses to maximize passive solar heating and cooling are basic processes used in the design and construction of green homes.

Guiding Principle – Resource efficiency

Most successful green homes started with the consideration of the environment at the design phase—the time at which material selection occurs. Creating resource efficient designs and using resource efficient materials can maximize function while optimizing the use of natural resources. For instance, engineered wood products can help optimize resources by using materials in which more than 50% more of the log is converted into structural lumber than conventional dimensional lumber [1].

Resource efficiency is also about reducing jobsite waste. Invariably, there are leftover materials from the construction process. Developing and implementing a construction waste management plan helps to reduce the quantity of landfill material. The average single-family home in the U.S., at 2,320 ft^2 (NAHB, 2003), is estimated to generate between 6,960 and 12,064 lbs. of construction waste. Thus, by creating an effective construction waste management plan and taking advantage of available recycling facilities and markets for recyclable materials, construction waste can be reduced by at least two-thirds, creating potential cost savings for builders and reducing the burden on landfill space.

Lastly, basing the selection of building materials on their environmental impact can be tricky. For instance, a product might be renewable, but on the other hand it takes a relatively great amount of energy to transport the product to a project's job site. While one way to compare products is to look at a product's or a home's life-cycle environmental impacts through a process called Life Cycle Analysis (LCA). An LCA of a building product covers its environmental impacts "cradle-to-grave" through six basic steps: 1) Raw material acquisition, 2) Product manufacturing process, 3) Home building process, 4) Home maintenance and operation, 5) Home demolition, and 6) Product reuse, recycling, or disposal. There are numerous reasons why building products are not commonly selected via LCAs. One of the issues is the availability of data – there is a lack of data to feed into tools that allow for an LCA on a product or system.

One such tool created by the National Institute of Standards and Technology (NIST) is the Building for Environmental and Economic Sustainability (BEES) software program. BEES has ten impact categories: Acid rain, Ecological toxicity, Eutrophication, Global warming, Human toxicity, Indoor air quality, Ozone depletion, Resource depletion, Smog, and Solid waste. Since information is not available to conduct full LCAs on all available building products, we have instead included an LCA mindset in creating the list of line items in the Resource Efficiency section. Our hope is that in the future the prescriptive line items in the guidelines will eventually be replaced with a full LCA approach for the home as a system and the components therein.

Guiding Principle – Energy efficiency

Energy consumption has far-reaching environmental impacts: from the mining of fossil fuel energy sources to the environmental emissions from burning non-renewable energy sources. And each home consumes energy year after year, meaning that the environmental impacts associated with that use accrue over time. Therefore, energy efficiency is weighted heavily in a green building program.

Energy consumption not only occurs during the operation of a home, but also during the construction of a home and, indirectly, in the production of the materials which go into the home. Although the energy used to heat and cool a home over its life far outweighs that to manufacture the materials and construct it, the large number of homes built (currently about 1.85 million per year) renders the energy used during the construction phase significant.

[1] www.healthyhomedesigns.com/information14.php

On average, a home built between 1990 and 2001 consumed about 12,800 kWh per year for space and water heating, cooling, and lights and appliances. Where natural gas is used, consumption averages 69,000 cubic feet per household annually. Total energy expenditures during a year cost these homeowners about $1,600[2]. Energy efficiency improvements that make a home 20% more efficient--a conservative estimate for many green homes--could significantly reduce a homeowner's annual utility bill expenses.

No matter what the climate, energy efficiency is considered a priority in most existing green building guidelines/programs. Moreover, as the cost to heat and cool a home becomes more unpredictable, it is advantageous to every homeowner to be "insulated" from inevitable utility bill increases. As with all aspects of these guidelines, the greatest improvements result from a "whole systems" approach. Energy performance does not end with increased R-values, the use of renewable energy, and/or more efficient HVAC equipment. Rather, there needs to be a balance between these features and careful window selection, building envelope air sealing, duct sealing, and proper placement of air and vapor barriers from foundation to attic to create a truly high-performance, energy-efficient home that is less expensive to operate and more comfortable to live in than a conventionally-constructed home.

Guiding Principle – Water efficiency

The mean per capita indoor daily water use in today's homes is slightly over 64 gallons. Implementing water conservation measures can reduce usage to fewer than 45 gallons[3]. For this reason, green homes are especially welcomed in areas affected by long- and short-term drought conditions.

The importance of water resources is becoming increasingly recognized, especially in the western third of the country. Choices between sending water to growing urban areas versus making water available for irrigation highlight the issues surrounding the scarcity of this valuable resource.

Green homes often conserve water both indoors and out. More efficient water delivery systems indoors and native and drought-resistant landscaping choices outdoors can help prevent unnecessary waste of valuable water resources. Communities can obtain additional benefits when builders effectively use native species in landscaping. Current research and practice has shown that natural processes can be a successful means of filtering and removing contaminants from storm water and wastewater.

Guiding Principle –Indoor environmental quality

Healthy indoor environments attract many people to green building. After energy efficiency, the quality of a home's indoor air is often cited as the most important feature of green homes. Pam Sessions, President of Hedgewood Properties in Atlanta, explained during the 2002 National Green Building Conference that the majority of people interested in green homes in the Atlanta market indicated that indoor air quality was their top issue of interest.

[2] 2001 RECS data
[3] American Water Works Association, *1997 Residential Water Use Summary - Typical Single Family Home*

An increase in reported allergies and respiratory ailments and the use of chemicals that can off-gas from building materials have contributed to a heightened awareness of the air we breathe inside our homes. Even though there is no authoritative definition of healthy indoor air, there are measures that can mitigate the effects of potential contaminants including: controlling the source, diluting the source, and capturing the source through filtration.

Guiding Principle – Operation, Maintenance and Homeowner Education

Improper or inadequate maintenance can defeat the designer's and builders best efforts to create a resource-efficient home. For example, homeowners often fail to change air filters regularly or neglect to operate bath and kitchen exhaust fans to remove moist air. Many homeowners are unaware of the indoor environmental quality impact of using common substances in and around the house such as pesticides, fertilizers, and common cleaning agents. By providing homeowners with a manual that explains proper operation and maintenance procedures, offers alternatives to toxic cleaning substances and lawn and garden chemicals, and points out water-saving practices, a builder can help assure that the green home that was so carefully built will also be operated in an environmentally responsible manner.

Guiding Principle – Global Impact

There are some issues related to home building and land development that do not fit nicely into the context of the aforementioned guiding principles. For these items that are a by-product of home construction, we have added a separate principle – global impact. One example of an issue having global impact is the selection of paints that contain relatively low or no volatile organic compounds (VOCs). Although the VOC content of paint is often considered for indoor environmental reasons, the vast majority of VOCs are released by the time the paint is dry. However, the release of VOCs from wet paint help form ground-level ozone pollution. Therefore, the use of low- or no-VOC paints falls under the global impact principle because the environmental impact of using paints with relatively high VOC levels is greater on the global scale than it is on the indoor environment

Guiding Principle - Site planning and land development

The process of green home building should not stop at the house. If a builder is also involved in the development of the community, site planning and land development can be part of the process. Therefore, information about low-impact site planning and land development is included in Appendix A. Considering the entire community and existing infrastructure in addition to the individual building(s) can amplify the benefits of green home building. For example, by improving a subdivision's storm water management plan and preserving natural resources through careful design and construction practices, a builder can influence not only the resource efficiency of each particular house but also the entire subdivision's overall environmental impact. Low Impact Development (LID), which uses various land planning and design practices and technologies to simultaneously conserve and protect natural resources and reduce infrastructure costs, is one way to approach green development.

How Homeowners Can Benefit from Green Building

The previous section highlighted the environmental benefits of green building practices. However, green building is much more than just reducing a home's environmental footprint. Homeowners can also realize direct benefits by owning a green home. Here are some of the primary benefits that owners of green homes have experienced compared to owners of conventional homes:

- **Lower operating costs** – Homeowners receive less expensive utility bills due to energy and water efficiency measures.
- **Increased comfort** – Green homes have relatively even temperatures throughout the home, with fewer drafts and better humidity control.
- **Improved environmental quality** – By following the attached guidelines, builders pay extra attention to construction details that control moisture, choose materials that contain fewer chemicals, and design air exchange/filtration systems that can contribute to a healthier indoor environment.
- **Enhanced durability and less maintenance** – Green homes incorporate building materials and construction details that strive to increase the useful life of the individual components and the whole house. Longer-lived materials not only require fewer resources for replacement but also reduce maintenance and the economic costs of repair. Green homes have lawns that require less weeding and watering, building elements that require less maintenance, and more durable building components that reduce the time needed for upkeep.

It is important to note that a builder can only do so much when it comes to how the home will perform. Homeowners play a big role in the house performance and, therefore, should be instructed on how to operate the green home as it was intended.

Guidelines Development Process

The NAHB Green Home Building Guidelines was developed through a public process that included the following major steps:

1. An extensive review of the existing local green home builder programs - primarily home builder association programs, but also including several public sector and non-profit programs. All but three of the 28 existing programs are voluntary and market-driven.
2. A review of the voluntary energy efficiency programs endorsed by the National Association of Home Builders (NAHB).
3. A review of the leading life cycle analysis (LCA) tools available for use by residential design and construction professionals in North America (e.g., BEES, ATHENA).
4. Input through an open process from numerous individuals on the NAHB Advisory Group and the Stakeholder Group.
5. Applying certain criteria to each line item in order to give the line items point values.

Each line item in the guidelines has a point value attributed to it. Once the Stakeholder Group members finalized the list of line items for inclusion in the guidelines, the NAHB Research Center team looked at each line item through three different lenses: 1) Environmental Impact, 2) Building Science and Best Building Practices, and 3) Ease of Implementation. The team used publicly available information, experiential data, and other data inputs to assign each line item points via these three criteria. Each line item's final point total was calculated by weighting the criteria. Environmental Impact received the greatest weight, followed by Building Science and Best Building Practices, with Ease of Implementation receiving the least weight.

Environmental Impact – The main purpose of these guidelines is to provide a framework for builders to reduce a home's environmental impact. We assessed how each line item helped make a home more energy efficient, improved indoor environmental quality, and so on. Assigning a value to each line item is an inexact science since all of the necessary data is not available. In addition, some line items had impacts that spanned multiple principles and, in some cases, the impact was positive for one guiding principle while negative for another. With that as background, the NAHB Research Center team took into account all of the above considerations and available data to assess the environmental impact of implementing each line item. Using qualitative and quantitative information, the team assigned value to each line item based on the positive impact to the environment.

Building Science and Best Building Practices – Certain green building practices dramatically impact how a house operates. For example, the sealing of a home's building envelope has an impact on the home's HVAC system. In addition, some measures such as proper flashing details and installation of weather barriers enhance durability, minimize the possibility of indoor environmental problems, and are considered "best building practices." Line items that help a home perform effectively as a system for the long-term were assigned a higher point value.

Ease of Implementation – Some line items are easier to implement than others. The NAHB Research Center team compared each line item to current home building practices and estimated how difficult it would be for a builder to implement the line item relative to primarily cost and time. For instance, would it take longer to install a new technology? Would subcontractors need to be educated on the use of a new product? Would a new technology cost more to buy? A line item will have a positive environmental impact only if it is implemented. Line items that were relatively easy to implement (and therefore more likely to be implemented) were assigned a greater point value than the items that are more difficult to implement.

Green Programs and Homes Differ Across the Country

When assigning points to the line items, the NAHB Research Center assumed the home would be built in Baltimore, MD, which is in Zone 4 of DOE's proposed climate zone map. The map can be viewed at the following URL:

http://www.energycodes.gov/implement/pdfs/color_map_climate_zones_Mar03.pdf

For associations located outside of Zone 4 that are interested in creating a green building program, point values can be customized for some line items most affected by climate conditions. For example, an association in Florida, you will likely want to increase the point values attributed to installing an energy efficient air conditioning system and decrease the point value associated with installing a high efficiency heating system. Similarly, in the southwestern United States associations would likely place higher value on water efficiency measures. A thermometer symbol 🌡 in the User Guide identifies line items that most likely will see point value changes due to climatic differences across the country.

Additional factors can lead to the decision to alter point values for a certain location, such as the availability of materials, the recycling marketplace, and the existence of rebate programs. Determining a line item's point value is accomplished by way of consensus among the members of the green home building program's development committee. This is primarily a qualitative process and some acknowledgment of the decision-making process should be clearly stated in the program.

Various Levels of "Green"

Homebuilders differ in their relative knowledge and comfort level with green building concepts. Some builders have been building green for years, while others are being introduced to the ideas for the first time. Recognizing this broad range of knowledge, the NAHB Research Center team established various thresholds to delineate different levels of green building effort.

The first step was to identify practices that should be part of any home building project. The first level of green building, Bronze, includes additional line items that in the end show that a builder paid special attention to a project's environmental impact. The next two levels of green home building, Silver and Gold, include additional line items that place increasingly greater emphasis on the home's environmental impact. The "How to Use the Guidelines" section of this document outlines how to score a home to determine if it meets or exceeds any of the green home building levels noted above.

The Uncertainties of Green Building

It should be noted that although many green building programs have been in existence for 10 years or more, the concept and practice of green building is not clearly defined and straightforward. Many gray areas remain in identifying and quantifying the precise environmental impact for each particular line item. For example, there is very little publicly available information regarding manufacturing processes that document energy consumption, impact on natural resources, or CO_2 emissions for each building material.

In addition, a particular guideline may contain tradeoffs and carry with it contradictory characteristics. For example, a recirculating hot water system can help save conserve water, but may use a relatively large amount of energy in its operation. Although the guidelines in their current form are based on experiential evidence and the latest independent scientific research available, they still may leave many questions unanswered due to the lack of scientific and quantitative data.

Finally, assigning a particular degree of importance to different criteria undoubtedly involves a certain amount of personal or local value judgment. Life Cycle Assessment (LCA) tools are beginning to sort out such questions, but the tools still remain in their infancy. Therefore, this set of green home building guidelines should be viewed as a dynamic document that will change and evolve as new information becomes available, improvements are made to existing techniques and technologies, and new research tools are developed.

How to Use the Guidelines

The guidelines are organized by the guiding principles listed above. However, there are two underlying ideas that everyone should keep in mind before undertaking a green home project. First, environmental considerations should be incorporated into the project from the very beginning. It is much harder to weave green home concepts into a project after the house plans are finished. Second, the house should be looked at as a whole as the builder determines which of the green home guideline items to put into the house. For example, making a home's building envelope tighter through air sealing and quality building techniques can affect the way in which the builder designs the home's ventilation system. It is through such a forward-thinking process that builders can gain cost efficiencies.

Part One – Green Home Building Checklist

Part One of these guidelines contains the checklist of line items. Each entry includes the line item title, the point value, and the items that should be provided by the builder to verify that the line item was implemented. The *verification* column assumes there is a green building program coordinator or other third-party. However, the guidelines and point system can be used independently even if a formal green building program does not exist in a particular region.

It is again recommended that a builder first become familiar with the line items prior to designing a home to help introduce concepts that a builder can incorporate into the home's design, construction, and operation.

To help a builder holistically incorporate green building into homes, the NAHB Research Center team established different point levels to achieve for each guiding principle for each level of green building. The point system is described below.

Point System

There are three different levels of green building available to builders wishing to use these guidelines to rate their projects – Bronze, Silver, and Gold[4]. At all levels, there are a minimum number of points required for each of the seven guiding principles in order to assure that all aspects of green building are addressed and that there is a balanced, whole-systems approach. After reaching the thresholds, an additional 100 points must be achieved by implementing any of the remaining line items. The table below outlines the various green building level thresholds.

Points Required for the Three Different Levels of Green Building

	BRONZE	SILVER	GOLD
Lot Design, Preparation, and Development	8	10	12
Resource Efficiency	44	60	77
Energy Efficiency	37	62	100
Water Efficiency	6	13	19
Indoor Environmental Quality	32	54	72
Operation, Maintenance, and Homeowner Education	7	7	9
Global Impact	3	5	6
Additional points from sections of your choice	100	100	100

* If the home does not have a ducted distribution system for space heating and cooling, deduct 15 points from the number of points required in the Energy Efficiency section.

A reduction in the required points for a home without ductwork for the space heating and cooling systems reflects the fact that there are more points available for homes that do have ductwork. It is not intended as an indication of preference for one type of system over another.

[4] A local program has the option to change the titles of each level of green building.

To determine point values for each guiding principle, a builder simply adds the points for each line item applied to the home for each guiding principle. Comparing the project's points for the individual guiding principles to the chart above will determine whether the project is deemed a Bronze, Silver, or Gold level green home.

Part Two – User Guide

Recognizing that some of the line items needed more than a one- or two-sentence explanation, the User Guide further explains each concept. For each line item, the User Guide contains an entry with the following subheadings:

Intent – Explains the general reasons for including each line item in the guidelines and the impact that implementing the line item will have on the environment.

Additional Information / How to Implement – Contains text, pictures, and formulas to help facilitate the line item's implementation.

Resources – References to books, Websites, articles, and technical guides for further in-depth information related to the line item. Please note that the URLs were active and current at the time this document was created. With the significant changes occurring on the Internet and in the home building industry products and services markets, location and availability of resources will most likely change over time.

As noted earlier, Appendix A provides additional ideas to consider for builders and developers who can affect change at the subdivision level, i.e., multiple home levels.

If a local green home building program does not exist, a builder can use the checklist and User Guide herein and self-certify a home. However, if a local association has used this document to create a local green building program, the builder can use the checklist and system from that program to show a home's relative green value.

Final Thoughts

We hope you find this tool useful and that it helps further advance green home building practices into mainstream construction. We wish you well in your endeavors and encourage you to share this information with your friends and family, customers, and product suppliers and distributors.

MODEL GREEN HOME BUILDING GUIDELINES

Part One
Model Green Home Building Checklist
Version 1

Section 1
Lot Design, Preparation, and Development

	PTS	HOW TO VERIFY
1.1 Select the site Select the site to minimize environmental impact.		
1.1.1. Avoid environmentally sensitive areas as identified through site foot-printing process or existing third party data.	7	<u>Any one of the following</u>: • Comprehensive Plan • Wetland Institute • Local jurisdiction's guidelines • Site foot-printing process results • Set of site plans
1.1.2 Choose an infill site.	9	
1.1.3 Choose a Greyfield site.	7	
1.1.4 Choose an EPA-recognized Brownfield.	7	Confirmation from a federal, state, or local Brownfield's site inventory list or representative that the site is a Brownfield
1.2 Identify goals with your team.		
1.2.1 Establish a knowledgeable team. A. Identify team member roles and how they relate to various phases of green lot design, prep, and development. B. Create a mission statement that includes the project's goals and objectives.	6	Written project mission statement, goals, and team member roles
1.3 Design the site. Minimize environmental impacts; protect, restore, and enhance the natural features and environmental quality of the site (points for each guideline are only rewarded upon implementation of these plans).		
1.3.1 Conserve natural resources.	6	Pre- and post-development

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		PTS	HOW TO VERIFY
	A. Complete a natural resources inventory used to drive/create the site plan. B. Create a protection and maintenance plan for priority natural resources/areas during construction. See Section 1.4 for guidance in forming the plan. C. Participate in a natural resources conservation program, e.g., Building *With* Trees. D. Provide basic training in tree and other natural resource protection to onsite supervisor.		natural resources inventory Protection and maintenance plan Certificate or letter indicating participation in a natural resources conservation program
1.3.2	Site the home and other built features to optimize solar resource (refer to Energy Efficiency module for guidance on solar resource optimization). (Note – do not include these points if you get points from 3.4.1.a or 3.4.1.b in the Energy Efficiency section)	6	House plans
1.3.3	Minimize slope disturbance. A. Limit development footprint on steep slopes (slopes greater than or equal to 25%). B. Complete a hydrological/soil stability study for steep slopes and use this study to guide the design of all structures onsite. C. Align road or extended driveway with natural topography to minimize its grade and reduce cut and fill. D. Reduce long-term erosion effects through the design and implementation of terracing, retaining walls, landscaping, and restabilization techniques.	5	Hydrological/soil stability study results Topographical map with contour lines
1.3.4	Minimize soil disturbance and erosion. See Section 1.4 for further guidance. A. Schedule construction activities to	6	Sediment and erosion control plans

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		PTS	HOW TO VERIFY
	minimize exposed soils. B. Use alternative means to install utilities, such as tunneling instead of trenching, use of smaller equipment, shared trenches or easements, and placement of utilities under streets instead of yards. C. Demarcate limits of clearing and grading.		
1.3.5	Manage storm water using low impact development. A. Preserve and use natural water and drainage features. B. Develop and implement storm water management plans that minimize concentrated flows and seek to mimic natural hydrology. C. Minimize impervious surfaces and use permeable materials for driveways, parking areas, walkways, and patios.	8	Storm water management plan
1.3.6	Devise landscape plans to limit water and energy demand while preserving or enhancing the natural environment. A. Formulate a plan to restore or enhance natural vegetation that is cleared during development. Within this plan, phase landscaping to ensure denuded areas are quickly vegetated. B. Select turf grass and other vegetation that are native or regionally appropriate species. C. Limit turf areas of landscaped area, selecting native and regionally appropriate trees and vegetation in a way that complements the natural setting. D. Group plants with similar watering needs (hydrozoning). E. Specify planting of trees to increase	8	Landscape plan

	PTS	HOW TO VERIFY
site shading and moderate temperatures (see also Energy Efficiency guideline 3.4.1.c specifying siting of trees to reduce the energy consumption of the home).		
F. Design vegetative wind breaks or channels as appropriate to local conditions.		
G. Require onsite tree trimmings or waste of regionally appropriate trees to be used as protective mulch during construction or as a base for walking trails.		
H. Establish an integrated pest management plan to minimize chemical use of pesticides and fertilizers.		
1.3.7 Maintain wildlife habitat.	5	Set of site plans (Extra points) Present a certificate or letter indicating participation in a wildlife conservation program.
1.4 Develop the site.		
Minimize environmental intrusion during onsite construction.		
1.4.1 Provide onsite supervision and coordination during clearing, grading, trenching, paving, and installation of utilities to ensure that targeted green development practices are implemented (see 1.3.4).	5	Protection and maintenance plan
1.4.2 Conserve existing onsite vegetation. A. Minimize disturbance of and damage to trees and other vegetation designated for protection through installation of fencing and avoidance of trenching, significant changes in grade, and compaction of soil and critical root	5	Protection and maintenance plan and/or set of site plans

	PTS	HOW TO VERIFY
zones. B. Prepare designated existing trees and vegetation for the impacts of construction through pruning, root pruning, fertilizing, and watering.		
1.4.3 Minimize onsite soil disturbance and erosion. A. Demarcate limits of clearing and grading. B. Create construction "no disturbance" zones using fencing or flagging to protect vegetation and sensitive areas from construction vehicles, material storage, and washout. C. Install and maintain sediment and erosion controls. D. Stockpile and cover good soil for later use. E. Reduce soil compaction from construction equipment through laying mulch, chipped wood, or plywood sheets. F. Stabilize disturbed areas within the EPA recommended 14-day period. G. Improve the soil with organic amendments and mulch.	6	Sediment and erosion control plans
1.5 Innovative options Seek to obtain waivers or variances from local development regulations to enhance green building.		
1.5.1 Share driveways or parking.	6	Waiver or variance for the plan
1.5.2 Other (specify).		Waiver or variance for the item(s)

Section 2
Resource Efficiency

	PTS	HOW TO VERIFY
2.1 Reduce quantity of materials and waste		
2.1.1 Create an efficient home floor plan that maintains a home's functionality.	9	House plans
2.1.2 Use advanced framing techniques that reduce the amount of home building material while maintaining the structural integrity of the home (see User Guide for examples).	8	House plans
2.1.3 Use building dimensions and layouts that maximize the use of the resources by minimizing material cuts.	6	House plans
2.1.4 Create a detailed framing plan and detailed material takeoffs. Provide an onsite cut list for all framing and sheathing material.	7	Framing plan Cut list
2.1.5 Use building materials that require no additional finish resources to complete application onsite.	4	Product literature Installer, manufacturer, or builder certified
2.1.6 Use pre-cut or pre-assembled building systems or methods		Framing plan
A. Provide a pre-cut (joist) or pre-manufactured (truss) floor and roof framing package – points provided for a flooring or a roof framing package – additional points provided if both packages are used	3 per	
B. Provide a panelized wall framing system	6	
C. Provide a panelized roof system	6	
D. Provide modular construction for the entire house	7	
2.1.7 Use a frost-protected shallow foundation (FPSF).	4	

	PTS	HOW TO VERIFY
2.2 Enhance durability and reduce maintenance Building design minimizes degradation and weathering of materials/enhances life expectancy. Features and details to be specified on architectural plans.		
2.2.1 Provide a covered entry (e.g., awning, covered porch) at exterior doors to prevent water intrusion and subsequent rotting of joists, sills, and finishes	6	House plans
2.2.2 Use recommended-sized roof overhangs for the climate	7	House plans
2.2.3 Install perimeter drain for all basement footings sloped to discharge to daylight, dry well, or sump pit	7	House plans
2.2.4 Install drip edge at eave and gable roof edges	6	House plans
2.2.5 Install gutter and downspout system to divert water 5' away from foundation and from there into the overall onsite drainage area	6	
2.2.6 Divert surface water from all sides of building. Slope top of backfill to achieve settled slope of at least 6" of fall within 10 feet of the foundation walls	7	Set of site plans
2.2.7 Install continuous and physical foundation termite barrier in areas where subterranean termite infestation is locally problematic.	7	
2.2.8 Use termite-resistant materials for walls, floor joists, trusses, exterior decks, etc. in areas known to be termite infested.	7	
2.2.9 Provide a water-resistive barrier (WRB) or a drainage plane system behind the exterior veneer system or the exterior siding.	8	
2.2.10 Install ice flashing at roof's edge	5	
2.2.11 Install enhanced foundation waterproofing	7	House plans

	PTS	HOW TO VERIFY
2.2.12 Employ and show on plans the following flashing details: A. Around windows and doors B. Valleys C. Deck/house juncture D. Roof/wall junctures, chimneys step flashing E. Drip cap above windows and doors	9	House plans
2.3 Reuse materials		
2.3.1 Disassemble existing buildings (deconstruction) instead of demolishing	6	
2.3.2 Reuse salvaged materials, where possible.	5	List of components
2.3.3 Dedicate and provide onsite bins and/or space to facilitate the sorting and reuse of scrap building materials.	6	C & D waste management plan
2.4 Use Recycled content materials		
2.4.1 Use recycled-content building materials	3	List of components used
2.5 Recycle waste materials during construction		
2.5.1 Develop and implement a construction and demolition (C & D) waste management plan that is posted at jobsite.	7	Copy of C & D waste management plan
2.5.2 Conduct onsite recycling efforts, e.g., use grinder and apply materials onsite, thus reducing transportation-related costs.	5	Copy of C & D waste management plan including information on what materials are going to be grinded for the project
2.5.3 Recycle construction waste offsite, e.g., wood, cardboard, metals, drywall, plastics, asphalt roofing shingles, concrete, block, other.	6	Contractual agreement between the recycling firm and the builder. Documentation on materials that have been recycled.

	PTS	HOW TO VERIFY
		List of components recycled
2.6 Use renewable materials		
2.6.1 Use materials manufactured from renewable resources (e.g., agricultural byproduct based products such as soy-based insulation; bamboo; wood-based products)	3	List of components used
2.6.2 Use certified wood for wood and wood-based materials and products from all credible third party certified sources, including A. The Sustainable Forestry Initiative® Program B. The American Tree Farm System® C. The Canadian Standards Association's Sustainable Forest Management System Standards (CAN/CSA Z809) D. Forest Stewardship Council (FSC) E. Program for the Endorsement of Forest Certification Systems (PEFC), and F. Other such credible programs as they are developed and implemented.	4	Certification certificate – points given per component
2.7 Use resource-efficient materials		
2.7.1 Use products that contain fewer resources to meet the same end-use as traditional products	3	List of components used
2.8 Innovative options		
2.8.1 Use locally available, indigenous materials	5	List of components used
2.8.2 Use a life cycle assessment (LCA) tool to compare the environmental burden of building materials and, based on the analysis, use the most environmentally preferable product for that building component.	8	Provide BEES or ATHENA output to show use of an environmentally preferable product

Section 3
Energy Efficiency

3.1 Implement integrated and comprehensive approach to energy-efficient design of building site, building envelope, and mechanical space conditioning systems

REQUIREMENTS – The home must meet the following conditions listed in 3.1.1 through 3.1.3 below.

The home must also achieve the equivalent of at least 37 Points (Bronze Level) from the optional guidelines in the Performance Path (Section 3.2) or the Prescriptive Path (Section 3.3).

	GUIDELINE	PTS	HOW TO VERIFY
3.1.1	Home is equivalent to the IECC 2003 or local energy code whichever is more stringent. Conformance to this threshold shall be based on plan analysis using software such as ResCheck or other as approved by green building program administrator.	Req.	ResCheck Analysis (only necessary if the local energy code does not at least meet the IECC 2003 requirements)
3.1.2	Size space heating and cooling system/equipment according to building heating and cooling loads calculated using ANSI/ACCA Manual J 8th Edition or equivalent. Computerized software recognized by ACCA as being in compliance with Manual J 8th Edition may be used.	Req.	Manual J load calculations
3.1.3	Conduct third party plan review to verify design and compliance with the Energy Efficiency section. When multiple homes of the same model are to be built by the same builder, a representative sample (15%) of homes may be reviewed subject to a sampling protocol.	Req.	Plan review may be completed by Green Building Program administrator, energy program administrators, architect/engineer, consultant, or other party outside of the Builder's company and acceptable to the Green Building Program administrator.

GUIDELINE	PTS	HOW TO VERIFY
3.2 Performance path		

An energy efficiency line item with a "**(PP)**" preceding it is a line item likely to be used to calculate X% above IECC 2003. If a builder chooses to use the performance path – line item 3.2.1 – to meet the guideline's energy efficiency requirements, then those measures with a "(PP)" cannot be used to obtain the 100 additional points from sections of your choice.

GUIDELINE	PTS	HOW TO VERIFY
3.2.1 Home is X% above IECC 2003		ResCheck Analysis
A. 15% (Bronze)	37	
B. 30% (Silver)	62	
C. 40% (Gold)	100	
3.3 Prescriptive path		
3.3.1 Building envelope		Builder-certified
(PP)A. Increase effective R-value of building envelope using advanced framing techniques, continuous insulation, and/or, integrated structural insulating system. Measures may include but are not limited to:		Approved by local program administrator Builder spec sheet
• SIPS*, or	8	
• ICFS*, or	8	
• Advanced Framing, or - Insulated corners and interior/exterior wall intersections* - Insulated headers on exterior walls	6	
• Raised heel trusses	2	
• Continuous insulation on exterior wall	4	
• Continuous insulation on cathedral ceiling	4	
* This line item also has a resource-efficiency benefit.		
(PP)B. Incorporate air sealing package to reduce infiltration. *(All measures that apply to project must be*	10	Builder-certified

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GUIDELINE	PTS	HOW TO VERIFY
performed.) 1. Sill sealer between foundation and sill plate. 2. Caulk bottom plate of exterior walls. 3. Air seal band joist cavities between floors. 4. Ensure air barrier continuity at all framed cavities such as air chases, soffits, coffered or dropped ceilings, and behind tub/shower units on exterior walls. Utilize either an interior or exterior air barrier as per local practice. 5. Caulk/foam all electrical, plumbing, heating penetrations between floors (including attic, basement, crawl space, and garage) and to exterior 6. Block and seal cantilevered floors and kneewalls. 7. Weatherstrip attic hatches, kneewall doors. 8. Insulate, caulk, or foam between window/door jambs and framing. 9. If installing recessed lights in ceilings adjacent to unconditioned space, use rated, air-tight Type IC housings. 10. Caulk/foam HVAC register boots that penetrate the building envelope to subfloor or drywall that penetrate the building envelope. 11. If a fireplace is installed, install a gas fireplace that is sealed combustion or a wood-burning fireplace with gasketed doors.		
(PP)C. Use ENERGY STAR® – rated windows appropriate for local climate.	8	Recommendation for local climate by Energy Efficient Windows Collaborative, www.efficientwindows.org

GUIDELINE	PTS	HOW TO VERIFY
3.3.2 HVAC design, equipment, and installation		
A. Size, design, and install duct system using ANSI/ACCA Manual D® or equivalent.	8	Manual D calculation
B. Design radiant or hydronic space heating systems using industry-approved guidelines, e.g., *Guidelines for the Design and Installation of Radiant Panel Heating and Snow/Ice Melting Systems* by the Radiant Panel Association, Heat Loss Guide (H-22), by the Hydronics Institute Division of GAMA or accredited design professionals and manufacturer's recommendations.	8	Documentation of design or design signed by professional
C. Use ANSI/ACCA Manual S® or equivalent to select heating and/or cooling equipment.	8	Manual S documentation
D. Verify performance of the heating/cooling system. HVAC contractor to perform the following: • Start-up procedure according to manufacturer's instructions • Refrigerant charge verified by super-heat and/or sub-cooling method • Burner set to fire at nameplate input • Air handler setting/fan speed • Total air flow within 10% of design flow • Total external system static should not exceed equipment capability at rated airflow.	8	Certification by HVAC contractor
E. Use HVAC installer and service technician certified by a nationally or regionally recognized program such as NATE, BPI, RPA, or manufacturers' training.	6	HVAC certification

GUIDELINE	PTS	HOW TO VERIFY
(PP)F. Fuel-fired space heating equipment efficiency (AFUE):		Certification by HVAC contractor
Gas Furnace ≥81%	4	
≥88% (ENERGY STAR)	6	
≥94%	8	
Oil Furnace: ≥83%	2	
Gas or Oil Boiler: ≥85%% (ENERGY STAR)	2	
>90%	6	
Note: Add 3 Points if Manual S and D and startup procedures are followed when one of the space heating units noted above is installed.		
(PP)G. Heat pump efficiency (cooling mode)		Certification by HVAC contractor
1. SEER 11-12*	4	
2. SEER 13-14	6	
3. SEER 15-18	6	
4. SEER 19+	7	
5. Staged air conditioning equipment	9	
Note: Split-systems must be ARI-tested as a matched set. *SEER 13 will be federal minimum as of January 2006. *Note: Add 3 points if Manual S and D and start-up procedures are followed when one of the ground source heat pumps noted above has been installed. Do not take these points again in 3.3.2.H.*		
(PP)H. Heat pump efficiency (heating mode)		Certification by HVAC contractor
1. 7.2-7.9 HSPF	6	
2. 8.0-8.9HSPF	7	
3. 9.0-10.5HSPF	9	
4. >10.5 HSPF	10	
Note: Split-systems must be ARI-tested as a matched set.		
(PP)I. Ground source heat pump installed by a Certified Geothermal Service Contractor. (cooling mode)		Certification by HVAC contractor The equipment supplier and

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GUIDELINE	PTS	HOW TO VERIFY
1. EER = 13-14 2. EER = 15-18 3. EER = 19-24 4. EER = >25 *Note: Add 3 points if Manual S and D and start-up procedures are followed when one of the ground source heat pumps noted above has been installed. Do not take these points again in 3.3.2.J.*	5 6 8 10	the contractor shall furnish, in writing, a "geothermal loop performance guarantee" stating that the heat rejection and absorption of the equipment will not exceed the geothermal loop design submitted and will consistently perform at or above specified efficiencies (taking into account water flow, air flow and entering water temperature).
J. **(PP)**Ground source heat pump installed by a Certified Geothermal Service Contractor. (heating mode)		Certification by HVAC contractor
1. COP 2.4 - 2.6	6	
2. COP 2.7 - 2.9	8	
3. COP ≥3.0	10	
K. Seal ducts, plenums, and equipment to reduce leakage. Use UL 181 foil tapes and/or mastic.	6	Certification by HVAC contractor
L. When installing ductwork:		Certification by HVAC contractor
1. No building cavities used as ductwork, e.g., panning joist or stud cavities. 2. Install all heating and cooling ducts and mechanical equipment within the conditioned building envelope. 3. No ductwork installed in exterior walls.	8	
M. Install return ducts or transfer grilles in every room having a door except baths, kitchens, closets, pantries, and laundry rooms.	6	Certification by HVAC contractor
N. Install ENERGY STAR ceiling fans. (Points per fan.)	1	Builder-certified
O. Install whole-house fan with insulated	4	Builder-certified

GUIDELINE	PTS	HOW TO VERIFY
louvers.		
P. Install ENERGY STAR labeled mechanical exhaust from every bathroom ducted to the outside.	8	Builder-certified
3.3.3 Water heating design, equipment, and installation		
A. Water heater Energy Factor (EF) equal to or greater than those listed in the following table.	4	Installer-certified

Gas	
Size (gallons)	Energy Factor
30	0.64
40	0.62
50	0.60
65	0.58
75	0.56
Electric	
30	0.95
40	0.94
50	0.92
65	0.90
80	0.88
100	0.86
Oil	
30	0.59
50	0.55

GUIDELINE	PTS	HOW TO VERIFY
B. Install whole house instantaneous (tankless) water heater. (Water heater complies with DOE Standard 10CFR430)	4	Installer-certified
C. Insulate all hot water lines with a minimum of 1" insulation.	4	Installer-certified
D. Install heat trap on cold and hot water lines to and from the water heater (if not integral to the water heater).	3	Installer-certified
E. Install manifold plumbing system with parallel piping configuration (aka	5	Installer-certified

GUIDELINE	PTS	HOW TO VERIFY
"home run") using smallest diameter piping allowed by code.		
3.3.4 Lighting and appliances		
A. Use an ENERGY STAR Advanced Lighting Package (ALP) in home.	7	Builder-certified
B. Install all recessed lighting fixtures within the conditioned envelope of the building, e.g., housing does not penetrate insulated ceiling.	7	Builder-certified
C. Install motion sensors on outdoor lighting (if not credited under 3.3.4.a).	7	Builder-certified
D. Install tubular skylights in rooms without windows.	2	Builder-certified
E. Install ENERGY STAR-labeled appliance:		Builder-certified
• Refrigerator	3	
• Dishwasher	3	
• Washing machine.	5	
3.3.5 Renewable energy/solar heating and cooling		Builder spec sheet
3.3.5.1 Solar space heating and cooling		
A. Use sun-tempered design: building orientation, sizing of glazing, design of overhangs to provide shading are in accordance with guidelines below:	10	
• Long side of the home faces within 30° of south;		
• Glazing area < 7% of Finished Floor Area (FFA) on south face (Low-E);		
• Glazing area < 2% of FFA on west face (Low-E, Low SHGC);		
• Glazing area < 4% of FFA on east face (Low-E, Low SHGC);		
• Glazing area < 4% of FFA on north face (Low-E);		
• Skylights less than 2% of Finished Ceiling Area, with shades and		

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GUIDELINE	PTS	HOW TO VERIFY
insulated wells; • Overhangs designed to provide shading on south-facing glass (at a minimum), or adjustable canopies or awnings. (See Users Guide for charts that indicate length of overhang, amount and period of shading according to latitude.)		
B. Use passive solar design: sun-tempered design as above plus additional south-facing glazing, appropriately designed thermal mass to prevent overheating, and provision for air flow to adjoining rooms. • Sun-tempered design as outlined above except additional glazing permitted on south wall <u>PLUS</u> • For any room with south-facing glazing > 7% of FFA, properly sized thermal mass, and • Provision for forced air flow to adjoining areas as needed. • (SBIC Passive Solar Design Guidelines for your climate should be referenced to size thermal mass.) *Note: 3.3.5.1.A must also be done in order to receive points for 3.3.5.1.B.*	10	Builder spec sheet specifying passive solar design features Documentation of design process
C. Use passive cooling. • Exterior shading on east and west windows, e.g., shade trees, moveable awnings or louvers, covered porches • Overhangs designed to provide shading on south-facing glazing. (Use supplied charts that indicate length of overhang, amount and period of shading according to latitude.) (Not to be double-counted if credited in 3.3.5.1.A above.) • Windows located to facilitate cross ventilation.	8	Builder spec sheet Documentation of design process Builder-certified

GUIDELINE	PTS	HOW TO VERIFY
• Solar reflective roof or radiant barrier in hot climates. *Note: All of the above must be done in order to receive points for this line item.*		
3.3.5.2 Solar water heating		
A. Install solar water heating system. Must use SRCC rated system. Solar fraction:		Installer-certified Manufacturers' specifications
1. 0.3	8	
2. ≥ 0.5	10	
3.3.5.3 Additional renewable energy options		
A. Supply electricity needs by onsite renewable energy source such as photovoltaics, wind or hydro whereby the system is estimated to produce the following kWh per year:		Installer-certified Manufacturers' specifications
2,000 to 3,999	8	
4,000 to 5,999	10	
6,000 +	12	
(Equipment should carry all applicable IEEE and UL certifications. Installation shall be in accordance with local utility and electrical code requirements.)		
B. Provide clear and unshaded roof area (+/-30°of south or flat) for future solar collector or photovoltaics. Minimum area of 200 sf. Provide a rough-in of piping from the roof to the utility area:		Builder-certified
• Conduit	3	
• Insulated piping	5	
C. Provide homeowner with information and enrollment materials about options to purchase green power from the local electric utility.	2	Builder-certified
(Not to duplicate points for Homeowner Manual in IEQ section below.)		
3.3.6 Verification	8	Inspection may be performed

GUIDELINE	PTS	HOW TO VERIFY
3.3.6.1 Conduct onsite third party inspection to verify installation of energy related features such as: A. Duct installation and sealing B. Building envelope air sealing details C. Proper installation of insulation including no gaps, voids, or compression D. Insulation cut accurately to fit cavity. E. Windows and doors flashed, caulked, and sealed properly. (When at least 100 homes of the same model are to be built by the same builder, a representative sample (15%) of homes may be inspected.)		by Green Building Program Administrator, energy program administrator, architect, engineer, or other party outside of the Builder's company and acceptable to the Green Building Program administrator. At least two onsite inspections should be done: one after insulation is installed and the second upon completion of the project.
3.3.6.2 Conduct third party testing to verify performance, e.g., blower door, duct leakage testing, flow hood testing, (per test). A. Building envelope leakage: blower door test results < 0.35 ACHnat B. Central HVAC duct leakage: duct leakage test results: • Leakage to unconditioned space < 5% of rated blower capacity. • Total leakage < 10% of rated blower capacity. C. Balanced HVAC air flows: flow hood test results: • Measured flow at each supply and return register within 25% of design flow. • Total air flow within 10% of design flow (When multiple homes of the same model are to be built by the same builder, a representative sample of homes may be tested subject to the sampling	8 per test	Report showing results of testing Examples of those who would be qualified to perform testing include but are not limited to energy program technicians, weatherization program technicians, HVAC contractors, and energy efficiency/ building science consultants.

GUIDELINE	PTS	HOW TO VERIFY
protocol.)		
3.3.7 Innovative options		
A. Install drain water heat-recovery system.	2	Installer-certified
B. Install desuperheater in conjunction with ground source heat pump.	6	Installer-certified
C. Install heat pump water heater. Must be rated according to the current US DOE test standard and shall have an EF > 1.7.	6	Installer-certified
D. Install occupancy sensors for lighting control. (Points per sensor.)	4	Builder-certified

Section 4
Water Efficiency

		PTS	HOW TO VERIFY
4.1 Indoor/Outdoor Water Use			
4.1.1	Hot water delivery to remote locations aided by installation of:	6	Installer-certified
	A. On-demand water heater at point of use served by cold water only. (Points per unit installed)		
	B. Control-activated recirculation system.		
4.1.2	Water heater located within 30 feet pipe run of all bathrooms and kitchen.	9	Installer-certified
4.1.3	ENERGY STAR® water-conserving appliances installed, e.g., dishwasher, washing machine.	7 per appl.	Installer-certified
4.1.4	Water efficient showerhead using conventional aerator or venturi technology for flow rate < 2.5 gpm.	2 per fix-ture	Installer-certified
4.1.5	Water-efficient sink faucets/aerators < 2.2 gallons/minute.	2 per fix-ture	Installer-certified
4.1.6	Ultra low flow (< 1.6 gpm/flush) toilets installed:		Installer-certified
	A. Power-assist	4	
	B. Dual flush.	6	
4.1.7	Low-volume, non-spray irrigation system installed, e.g., drip irrigation, bubblers, drip emitters, soaker hose, stream-rotator spray heads.	7	Installer-certified
4.1.8	Irrigation system zoned separately for turf and bedding areas.	6	Installer-certified
4.1.9	Weather-based irrigation controllers, e.g., computer-based weather record.	7	Installer-certified
4.1.10	Collect and use rainwater as permitted by local code. (Additional credit for distribution system	9	Builder-certified

		PTS	HOW TO VERIFY
	that uses a renewable energy source or gravity.)		
4.1.11	Innovative wastewater technology as permitted by local code, e.g., constructed wetland, sand filter, and aerobic system.	7	Submit plan approved by local code or health department official

4.2 Innovative options

		PTS	HOW TO VERIFY
4.2.1	Shut-off valve, motion sensor, or pedal-activated faucet to enable intermittent on/off operation.	6	Installer-certified
4.2.2	Separate and re-use greywater as permitted by local code.	6	Installer-certified
4.2.3	Composting or waterless toilet as permitted by local code.	6	Installer-certified

Section 5
Indoor Environmental Quality

		PTS	HOW TO VERIFY
5.1 Minimize potential sources of pollutants			
5.1.1	For vented space heating and water heating equipment: A. Install direct vent equipment. Or B. Install induced/mechanical draft combustion equipment.	8	Builder spec sheet
5.1.2	Install space heating and water heating equipment in isolated mechanical room or closet with an outdoor source of combustion and ventilation air.	6	Builder spec sheet
5.1.3	Install direct-vent, sealed-combustion gas fireplace, sealed wood fireplace, or sealed woodstove. Or No fireplace or woodstove installed.	6	Builder spec sheet
5.1.4	Ensure a tightly-sealed door in between the garage and living area and provide continuous air barrier between garage and living areas including air sealing penetrations, walls, ceilings, and floors.	9	Builder spec sheet
5.1.5	Ensure particleboard, medium density fiberboard (MDF) and hardwood plywood substrates are certified to low formaldehyde emission standards ANSI A208.1, ANSI A208.2 and ANSI/HPVA HP1, respectively. Composite wood/agrifiber panel products must either contain no added urea-formaldehyde resins or must be third party certified for low formaldehyde emissions.	6	Manufacturer's spec sheet Third-party listing
5.1.6	Install carpet, carpet pad, and floor covering adhesives that hold "Green Label" from Carpet and Rug Institute's indoor air quality testing program or meet equivalent thresholds verified by a third party.	6	Manufacturer's spec sheet Third-party listing
5.1.7	Mask HVAC outlets during construction and vacuum ducts, boots, and grilles before turning on central heating/cooling system.	5	

	PTS	HOW TO VERIFY
5.1.8 Use low VOC emitting wallpaper.	3	Builder's spec sheet
5.2 Manage potential pollutants generated in the home		
5.2.1 Vent kitchen range exhaust to the outside.	7	Builder spec sheet Use Guidance in Homeowner's Manual
5.2.2 Provide mechanical ventilation at a rate of 7.5 cfm per bedroom + 7.5 cfm and controlled automatically or continuous with manual override. The ventilation equipment may be:		Builder spec sheet Use guidance in Homeowner's Manual
A. Exhaust or supply fan(s), or	7	
B. Balanced exhaust and supply fans, or	9	
C. Heat-recovery ventilator, or	10	
D. Energy-recovery ventilator	10	
5.2.3 Install MERV 9 filters on central air or ventilation systems.	3	Use guidance in Homeowner's Manual
5.2.4 Install humidistat to control whole-house humidification system.	4	Use guidance in Homeowner's Manual
5.2.5 Install sub-slab de-pressurization system or infrastructure to facilitate future installation of radon mitigation system. *The more stringent requirement between a local building code and this provision shall apply.	6	Builder spec sheet
5.2.6 Verify all exhaust flows meet design specifications	9	
5.3 Moisture management (vapor, rainwater, plumbing, HVAC)		
5.3.1 Control bathroom exhaust fan with a timer or humidistat.	6	Builder spec sheet (Not to duplicate points from 5.2.b)
5.3.2 Install moisture resistant backerboard – not paper-faced sheathing – under tiled surfaces in wet areas.	6	Builder spec sheet

		PTS	HOW TO VERIFY
5.3.3	Install vapor retarder directly under slab (6-mil) or on crawl space floor (8-mil). In crawl spaces, extend poly up wall and affix with glue and furring strips, or damp-proof wall below grade. Joints lapped 12 inches.	9	Builder spec sheet
5.3.4	Protect unused moisture-sensitive materials from water damage through just-in-time delivery, storing unused materials in a dry area, or tenting materials and storing on a raised platform.	6	Builder's moisture management practice or plan
5.3.5	Keep plumbing supply lines out of exterior walls.	5	
5.3.6	Insulate cold water pipes in unconditioned spaces with ½" insulation or other coating that comparably prevents condensation.	4	Builder's Specs
5.3.7	Insulate HVAC ducts, plenums, and trunks in unconditioned basements and crawl spaces to avoid condensation.	4	Builder's Specs
5.3.8	Check moisture content of wood before it is enclosed on both sides. Ensure moisture content of subfloor/substrate meets the appropriate industry standard for the finish flooring material to be installed.	4	Builder's moisture management practice or plan

5.4 Innovative options

Section 6
Operation, Maintenance, and Homeowner Education

	PTS	HOW TO VERIFY
6.1 Provide Home Manual to owners/occupants on the use and care of the home. Manual must include all items below:		
A. Narrative detailing the importance of maintenance and operation to keep a green built home green	9	Copy of the Home Manual
B. Local Green Building Program certificate.		
C. Warranty, operation, and maintenance instructions for equipment and appliances		
D. Household recycling opportunities		
E. Information on how to enroll in a program so that the home receives energy from a renewable energy provider		
F. Explanation of the benefits of using compact fluorescent light bulbs in high usage areas		
G. A list of habits/actions to optimize water and energy use		
H. Local public transportation options (if applicable)		
I. Clearly labeled diagram showing safety valves and controls for major house systems.		
6.2 Optional information to include in the Home Manual (Choose at least 5)		
A. A list of local service providers that focus on regularly scheduled maintenance and proper operation of equipment and the structure (sealants, caulks, gutter and downspout system; shower/tub surrounds, irrigation systems, etc).	2	
B. A photo record of framing with utilities installed. Photos should be taken prior to installing insulation, clearly marked, and provided in homeowner's manual.		
C. List of Green Home Building Guidelines items		

	PTS	HOW TO VERIFY
included in the home.		
D. User-friendly maintenance checklist		
E. Instructions for proper handling and disposal of hazardous materials.		
F. Information on organic pest control, fertilizers, de-icers and cleaning products.		
G. Information about native or low-water landscape		
H. Information on how to keep a home's relative humidity in the range of 30-60%		
I. Instructions for checking crawlspace for termite tubes periodically		
J. Instructions for keeping gutters clean. Instructions should note that downspouts should divert water at least five feet away from foundation		
6.3 Provide education to owners/occupants in the use and care of their dwellings.		
A. Instruct homeowner/occupants about the building's goals and strategies and occupant's impacts on costs of operating the building. Provide training to owners/occupants for all control systems in the house.	7	
6.4 Solid waste		
A. Encourage homeowners/occupants to recycle by providing built-in space in the home's design (e.g., kitchen, garage, covered outdoor space) for recycling containers.	1	
6.5 Innovative options		

Section 7
Global Impact

	PTS	HOW TO VERIFY
7.1 Products		ISO 14001 certification
7.1.1 Product manufacturer's operations and business practices include environmental management system concepts (the product line, plant, or company must be ISO 14001 certified)	3	
7.1.2 Choose low- or no-VOC indoor paints. VOC concentrations (grams/liter) of interior paints should be equal to or less than those specified by the EPA's Environmentally Preferable Purchasing Program: • Interior latex coatings: Flat: 100 grams/liter; Non-flat: 150 grams/liter • Interior oil-based paints: 380 grams/liter	6	Builder's spec Manufacturer's spec or third-party listing
7.1.3 Use low VOC sealants. VOC concentrations for construction adhesives and sealants should meet the limits specified in the California Air Resources Board Regulation for Reducing Volatile Organic Compound Emissions from Consumer Products: • Construction adhesives: the greater of 15% by weight or 200 grams/liter • Sealants and caulks: the greater of 4% by weight or 60 grams/liter • Contact adhesives: the greater of 80% by weight or 650 grams/liter	5	Manufacturer's spec or third-party listing
7.2 Innovative options		
7.2.1 Builder's operations and business practices include environmental management system concepts (the builder must be ISO 14001 certified)	4	ISO 14001 certification

Appendix A – Site Planning and Land Development[5]

	PTS	HOW TO VERIFY
1.0 Identify goals with your team		
• Establish a knowledgeable team and communicate in writing.		Written list of team members
• Establish a "green development" mission statement.		Written project mission statement
• Identify goals and objectives.		Written project goals
• Identify team member roles and how they relate to various phases of development.		Written project team member roles
• Provide training to onsite supervisors and team members on the green development practices that will be instituted onsite.		Training materials information
• Create a checklist to be filled out onsite that contains only those targeted green development practices that will be implemented in this project (see guideline 4a for execution of this checklist).		Checklist of green development practices that will be implemented
2.0 Select the site		
Select the site to minimize environmental impact.		
• Avoid environmentally "sensitive areas" as identified through site foot printing process or third party.		Any one of the following: Comprehensive Plan Wetland Institute Local jurisdiction's guidelines Site foot printing process results Set of site plans
• Choose an EPA recognized Brownfield (see User Guide for definition).		Confirmation from a Federal, state, or local Brownfield site inventory list or representative that the site is a Brownfield

[5] Appendix A is intended to be used at the development scale, whereas Section 1 of the checklist is for individual lots.

	PTS	HOW TO VERIFY
• Choose a Greyfield site (see User Guide for definition).		
• Choose an infill site (see User Guide for definition).		

3.0 Design the site

Minimize environmental impacts; protect, enhance, and restore the natural features and environmental quality of the site (points for each guideline are only rewarded upon execution of these plans).

	PTS	HOW TO VERIFY
• Conserve natural resources.		Pre- and post-development natural resources inventory
• Complete a natural resources inventory that is used to drive/create the site plan.		Protection and maintenance plan
• Create a protection and maintenance plan for priority natural resources/areas during construction. See section 4 for guidance in forming the plan.		Certificate or letter indicating participation in a natural resources conservation program
• Locate roads, buildings, and other built features to conserve high priority vegetation.		
• Participate in a natural resource conservation program.		
• Orient streets and configure lots to allow for the majority of homes to optimize solar potential (see the Energy Efficiency Module for guidance on solar resource optimization)		House plans
• Minimize slope disturbance.		Hydrological/soil stability study results
• Limit development footprint on steep slopes (slopes greater than or equal to 25%).		Topographical map with contour lines
• Complete a hydrological/soil stability study for steep slopes and use this study to guide the design of all structures onsite.		
• Align roads with natural topography to minimize its grade to reduce cut and fill.		
• Reduce long-term erosion effects through the design and implementation of terracing, retaining walls, landscaping, and restabilization techniques.		
• Minimize soil disturbance and erosion.		Sediment and erosion control plans
• Phase development to minimize exposed soils.		

	PTS	HOW TO VERIFY
• Use alternative means to install utilities, such as tunneling instead of trenching, use of smaller equipment, shared trenches or easements, and placement of utilities under streets instead of yards.		
• Manage storm water properly.		Storm water management plan
• Direct storm water to a locally approved regional storm water management and treatment facility that has been designed to address water quality.		
• Preserve and utilize natural water and drainage features.		
• Develop and implement storm water management plans that minimize concentrated flows and seek to mimic natural hydrology.		
• Minimize impervious surfaces and utilize permeable materials for • Parking areas • Walkways • Streets - minimize street widths and rights-of-way as per recommendations in either local code or in *Residential Streets*, 3rd Edition: a. No on-street parking: 18 feet b. Parking on one side: 22 – 24 feet c. Parking on both sides: 24 – 26 feet		
• Use an advanced wastewater system as an alternative to the conventional septic system and drain field, where municipal sewage is not available. Examples include sand/media filters aerobic treatment units, and community package plants.		System specifications
• Devise landscape plans to limit water demand while preserving or enhancing the natural environment.		Landscape plan
• Formulate a plan to restore or enhance natural vegetation that is cleared during construction or development. Within this plan, phase landscaping to ensure denuded areas are quickly vegetated.		
• Select turf grass and other vegetation that are native or regionally appropriate species.		
• Limit turf areas of landscaped area, selecting native and regionally appropriate trees and vegetation in a		

	PTS	HOW TO VERIFY
way that complements the natural setting.		
• Group plants with similar watering needs (hydrozoning).		
• Specify planting of trees to increase site shading and moderate temperatures (see also Energy Efficiency guideline 3.3.5.1 specifying siting of trees to reduce the energy consumption of the home).		
• Require onsite tree trimmings of regionally appropriate species to be used as protective mulch during construction or as a base for walking trails.		
• Establish an integrated pest management plan to minimize chemical use in pesticides and fertilizers.		
• Maintain wildlife habitat. • Preserve open space as wildlife corridors where possible. • Institute wildlife habitat measures • Participate in a wildlife conservation program.		Certificate or letter indicating participation in a wildlife conservation
• Prepare operation and maintenance plan (manual) for transfer of common open spaces, utilities (storm water, waste water), and environmental management.		Copy of the manual
• Disassemble existing buildings and reuse or recycle the building materials (deconstruction) instead of demolishing.		Catalogue reused or recycled building materials
4.0 Develop the site		
Minimize environmental intrusion during onsite construction.		
• Provide onsite supervision and coordination during clearing, grading, trenching, paving, and installation of utilities to ensure that targeted green development practices are implemented.		Protection and maintenance plan
• Conserve existing onsite vegetation. • Provide basic training in tree and other natural resource protection to onsite supervisor. • Minimize disturbance of and damage to trees and other vegetation designated for protection through		Protection and maintenance plan and/or set of site plans

	PTS	HOW TO VERIFY
installation of fencing and avoidance of trenching, significant changes in grade, and compaction of soil and critical root zones.		
• Prepare designated existing trees and vegetation for the impacts of construction through pruning, root pruning, fertilizing, and watering.		
• Improve the soil with organic amendments and mulch.		
• Minimize onsite soil disturbance and erosion.		Sediment and erosion control plans
• Demarcate limits of clearing and grading.		
• Create construction "no disturbance" zones using fencing or flagging to protect vegetation and sensitive areas from construction vehicles, material storage, and washout.		
• Install and maintain sediment and erosion controls.		
• Stockpile and cover good soil for later use.		
• Reduce soil compaction from construction equipment through laying mulch, chipped wood, or plywood sheets.		
• Stabilize disturbed areas within the EPA recommended 14-day period.		
5.0 Innovative options		
Seek to obtain waivers or variances from local development regulations to enhance green building.		
• Cluster development to preserve meaningful open space.		Set of site plans
• Reduce street widths.		Set of site plans
• Share driveways or parking.		Set of site plans
• Other (specify).		

NAHB MODEL GREEN HOME BUILDING GUIDELINES

Part Two
MODEL GREEN HOME BUILDING USER GUIDE
VERSION 1

NAHB RESEARCH CENTER

DISCLAIMER

This publication contains guidance for builders engaged in or interested in green building products and practices for residential design, development and construction. This publication is not intended to be exhaustive and all-inclusive and the enclosed guidelines are not to be considered the only method of green building. These guidelines for green building originate from the collective experience of leading personnel in the green building movement (marketplace), but must, due to the nature of the responsibilities involved, be presented only as a guide for the use of a qualified developer, builder, remodeler, or design professional.

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SECTION 1
LOT DESIGN, PREPARATION, AND CONSTRUCTION

1.1 Select the site

1.1.1 Avoid environmentally "sensitive areas" as identified through site foot-printing process or existing third party data.

Intent:

Thoughtful site selection can be the first step in building a green home. By avoiding environmentally sensitive areas, a builder can help preserve land that might function as a corridor for wildlife, recreational open space, or habitat sanctuary. By selecting a site that has at any time been identified as an environmentally sensitive area, a builder will receive no credit for this line item, regardless of the site's classification at the time of construction.

Additional Information / How to Implement:

"Sensitive areas" may be identified within a comprehensive plan, by a wetland institute, or by the local jurisdiction. Other excellent sources of detailed environmental information about a site are professionals such as arborists, landscape architects, ecologists, and wildlife biologists. These experts can provide assistance in identifying a potential site's natural resources and environmentally sensitive areas.

Resources:

- American Society of Consulting Arborists, http://www.asca-consultants.org/why.html.
- American Society of Landscape Architects, http://www.asla.org/members/pigroups.cfm.
- International Society of Arboriculture, http://www.isa-arbor.com/home.asp.
- Society of American Foresters, http://www.safnet.org/certifiedforester/.
- The Ecological Society of America, http://www.esa.org/.

1.1.2 Choose an infill site.

Intent:

Building on an infill site can effectively conserve resources (e.g., infrastructure) and preserve open space that could be lost from "green field" development.

Additional Information / How to Implement:

Infill areas are vacant or underutilized lots of land, served by existing physical installations such as roads, power lines, sewer and water, and other infrastructure.

Resources:

- Policy Link, Equitable Development Toolkit, Infill Incentives, http://www.policylink.org/EDTK/Infill/.
- Northeast-Midwest Institute and Congress for the New Urbanism, *Strategies for Successful Infill Development* (2001), http://www.nemw.org/infillbook.htm.

1.1.3 Choose a Greyfield site.

Intent:

Redevelopment of a Greyfield site can provide an efficient use of land and infrastructure. Greyfield redevelopment allows for the preservation of open space and wildlife habitat in the midst of growth.

Additional Information / How to Implement:

Within these guidelines, a Greyfield is defined as "any site previously developed with at least 50% of the surface area covered with impervious material." The development of a Greyfield site can be daunting, but local or national incentives may exist to reward those builders who go through the process. Incentives may include the elimination of development related fees, contribution from the local government in the development of off-site improvements, and tax breaks. For more information, contact the Congress for the New Urbanism, Urban Land Institute, American Planning Association, or the International Council of Shopping Centers.

Resources:

- Congress for the New Urbanism, www.cnu.org.
- Urban Land Institute, www.uli.org.
- American Planning Association, www.planning.org.
- International Council of Shopping Centers, www.icsc.org.
- Congress for the New Urbanism and PricewaterhouseCoopers, *Greyfields into Goldfields: From Falling Shopping Centers to Great Neighborhoods* (February 2001), http://www.cnu.org/cnu_reports/Executive_summary.pdf.
- Congress for the New Urbanism and PricewaterhouseCoopers, *Greyfield Regional Mall Study* (January 2001), http://www.cnu.org/cnu_reports/Greyfield_Feb_01.pdf.

1.1.4 Choose an EPA-recognized Brownfield.

Intent:

Remediation of a Brownfield results in the environmental restoration of a polluted site, a transformation that makes an abandoned site habitable. Like Greyfield and infill development, Brownfield development provides an efficient use of land and infrastructure while allowing for the preservation of open space and wildlife habitat in the midst of growth.

Additional Information / How to Implement:

The U.S. Environmental Protection Agency (EPA) characterizes Brownfields as "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." The EPA estimates that there are 450,000 such sites around the country. Grants, loans, and training are available through the EPA's Brownfield Initiative to assist builders and developers in the remediation and development of Brownfield sites.

Resources:

- U.S. Environmental Protection Agency, Brownfields Cleanup and Redevelopment: http://www.epa.gov/Brownfields/index.html.
- U.S. Environmental Protection Agency has introduced two Web-based tools to give the public additional access to information about Brownfield properties and cleanup efforts. The tools allow residents to locate Brownfields in their area and provide access to information about cleanup grants. - www.epa.gov/Brownfields/bfwhere.htm

1.2 Identify goals with your team

1.2.1 Establish a knowledgeable team.

A. Identify team member roles and how they relate to various phases of "green" lot design, prep, and development.

B. Create a mission statement that includes the project's goals and objectives.

Intent:

One of the earliest challenges for a builder in developing a "green" lot is assembling an effective team to help the builder implement best "green" practices throughout the process. Those involved in the development phase must understand what the mission of the site is, what it means to be a "green" lot, and why "green" practices should be followed. Once this baseline is established, coordination and communication with and among the various team members is essential to successfully develop a "green" lot.

Additional Information / How to Implement:

Before ground is broken, all parties that will be involved in lot development (i.e., the team) should understand that the lot will be developed as a "green" site. Examples of possible team members include staff, site superintendents, utilities, excavators, landscape architects, wildlife biologists, ecologists, and arborists. Once the "green" intent of the builder is communicated to the lot development team, the builder should work with the team throughout the development process to identify and delegate responsibilities of team members, as well as facilitate coordination between the members to achieve best green practices.

Resources:

- American Society of Consulting Arborists, http://www.asca-consultants.org/why.html.
- American Society of Landscape Architects, http://www.asla.org/members/pigroups.cfm.
- International Society of Arboriculture, http://www.isa-arbor.com/home.asp.
- Society of American Foresters, http://www.safnet.org/certifiedforester/.
- The Ecological Society of America, http://www.esa.org/.

1.3 Design the site

Minimize environmental impacts; protect, restore, and enhance the natural features and environmental quality of the site.

1.3.1 Conserve natural resources.

A. Complete a natural resources inventory used to drive/create the site plan.

B. Create a protection and maintenance plan for priority natural resources/areas during construction. See Section 1.4 for guidance in forming the plan.

C. Participate in a natural resources conservation program, e.g., Building *with* Trees.

D. Provide basic training in tree and other natural resource protection to onsite supervisor.

Intent:

Onsite natural resources concern such features as solar energy availability, flora, fauna, water, soil, and geological formations. A natural resources inventory should be completed to identify the site's environmental attributes. Based on this inventory, a builder can then identify high priority resources for conservation (e.g., trees, waterway, snags, and micro-habitats) and plan for the conservation of those resources during each stage of site development.

Additional Information / How to Implement:

On complex sites, a natural resources inventory may be performed by a qualified professional such as an arborist, wildlife biologist, or landscape architect. Simpler sites, such as previously developed sites or farmland, might be adequately inventoried by knowledgeable, but less qualified, individuals. Whoever ultimately conducts the inventory should be able to discern between invasive and regionally appropriate vegetation, understand how to site a house to achieve maximum solar energy potential, be able to identify areas important to wildlife habitat, and understand how natural features can be used in managing storm water onsite.

A protection and maintenance plan should be drafted to detail how resources identified through the inventory will be protected throughout development. Section 4 of this module describes how to protect existing onsite vegetation and minimize soil disturbance and erosion through such means as installation of fencing, identification of specified washout and material storage areas, lying of mulch to reduce soil compaction, etc. In addition to protecting priority areas from intrusion during development, a maintenance plan should be created to ensure that priority vegetation survives development. Within the maintenance plan, include plans and information on fertilizing and watering trees as needed before, during, and after development.

One way to verify that the plan is implemented as planned is to create construction documents that explain how to implement the plan at each phase.

Resources:

- American Society of Consulting Arborists, http://www.asca-consultants.org/why.html.

- American Society of Landscape Architects, http://www.asla.org/members/pigroups.cfm.
- International Society of Arboriculture, http://www.isa-arbor.com/home.asp.
- Society of American Foresters, http://www.safnet.org/certifiedforester/.
- Article on preserving trees during construction: http://www.umass.edu/bmatwt/publications/articles/preserving_trees_during_construction.html

1.3.2 Site the home and other built features to optimize solar resource (refer to Energy Efficiency module for guidance on solar resource optimization). (Note – do not include these points if you get points from 3.3.5.1.a or 3.3.5.1.b in the Energy Efficiency section)

Intent:

Thoughtful orientation of a home can maximize solar heating potential in the heating season and minimize solar gains in the cooling season. Orienting a home to optimize its solar resource reduces energy use and, therefore, reduces the pollution caused by a home during its life.

Information / How to Implement:

There are many factors to consider when siting a home. A builder should consider such issues such as slope, storm water management, local solar angles, and high priority vegetation when determining the optimum site for each home. The final decision in siting generally involves a compromise between these many factors.

Resources:

See section 3.3.5.1.a or 3.3.5.1.b of this User Guide for resources.

1.3.3 Minimize slope disturbance.

A. Limit development footprint on steep slopes (slopes greater than or equal to 25%).

B. Complete a hydrological/soil stability study for steep slopes and use this study to guide the design of all structures onsite.

C. Align road or extended driveway with natural topography to minimize its grade and reduce cut and fill.

D. Reduce long-term erosion effects through the design and implementation of terracing, retaining walls, and restabilization techniques.

Intent:

Leaving a slope undisturbed reduces the risk of disturbing natural hydrological drainage and causing long and short-term erosion on the site, which can pollute water sources and damage local ecology.

Additional Information / How to Implement:

Within these guidelines, steep slopes are defined as those slopes that are greater than or equal to 25%. *Note: points should only be awarded if there are developable steep slopes in the area.*

Reduce cut and fill practices to help prevent unnecessary stripping of vegetation and loss of soils and reduce the need for additional resources to be brought in from off-site.

Resources:

- Prince George's County, Maryland, Department of Environmental Resources, *Low-Impact Development Design Strategies: An Integrated Design Approach* (EPA 841-B-00-003) (Largo, MD: June 1999), http://www.epa.gov/owow/nps/lid/lidnatl.pdf.

1.3.4 Minimize soil disturbance and erosion. See Section 1.4 for further guidance.

A. Schedule construction activities to minimize time that soil is exposed.

B. Use alternative means to install utilities, such as tunneling instead of trenching, use of smaller equipment, shared trenches or easements, and placement of utilities under streets instead of yards.

C. Demarcate limits of clearing and grading.

Intent:

Sediment and the pollutants contained in it are recognized sources of water quality problems. Exposed soils should be minimized to reduce erosion, promote water quality, and reduce damage caused to native vegetation. Heavy equipment and excessive digging can result in compaction or loss of topsoil along with the introduction of invasive and problematic flora. Minimizing soil disturbance and erosion both reduces stressors on downstream water bodies and saves valuable topsoil for the site.

Additional Information / How to Implement:

NAHB's *Storm Water Permitting: A Guide for Builders and Developers* contains information about the federal Phase I and II storm water permitting program and the equivalent requirements for state storm water permits (see Resources section). Storm Water Permitting also contains technical information, including recommendations for use and cost estimates, on over 50 of the most commonly used Best Management Practices; sample Storm Water Pollution Prevention Plans; and tips on compliance, including how to handle visits from inspectors.

Methods for preventing erosion include silt fences, sediment traps, vegetated buffer areas, and mulching. More permanent solutions include biomechanical devices such as swales and vegetated buffers. Another highly effective, environmentally responsible method to preventing erosion is to use compost filter berms, compost erosion socks and/or surface application of compost erosion control. The compost should be from organic sources like bioshields, yard waste, and wood chips. Turf and plant material - which help to facilitate the reestablishment of a natural environment – are established more quickly when organic compost is used.

Resources:

- ❖ National Association of Home Builders (NAHB), *Storm Water Permitting: A Guide for Builders and Developers,* 2004, http://store.builderbooks.com or 800-368-5242 x8163.
- ❖ King County Department of Natural Resources, King County, *Washington Surface Water Design Manual Appendix D: Erosion and Sediment Control Standards* (Seattle: September 1998), ftp://ftp.metrokc.gov/ddes/acrobat/esa/kcswdm-d.pdf.
- ❖ Dr. James R. Fazio, National Arbor Day Foundation, *Trenching and Tunneling: A Pocket Guide for Qualified Utility Workers* (Nebraska City, Nebraska: 1998), http://www.arborday.org/shopping/merchandise/merchdetail.cfm?id=62.

1.3.5 Manage storm water using low impact development.

A. Preserve and utilize natural water and drainage features.

B. Develop and implement storm water management plans that minimize concentrated flows and seek to mimic natural hydrology.

C. Minimize impervious surfaces and use permeable materials for driveways, parking areas, walkways, and patios.

Intent:

Percolation through soil is one of the most effective means for filtering pollutants carried by storm water. By using natural water and drainage features, minimizing impervious surfaces, and distributing storm water flows, builders can reduce harmful pollutants carried off site while safely and effectively managing much of their storm water load onsite.

Additional Information / How to Implement:

Use open space and natural systems such as vegetative swales, french drains, wetlands, drywells, and rain gardens that promote water quality and infiltration.

Resources:

- ❖ The Practice of Low Impact Development, U.S. Department of Housing and Urban Development (HUD); http://www.huduser.org/publications/destech/lowimpactdevl.html
- ❖ Tom Schueler, Center for Watershed Protection, *Site Planning for Urban Stream Protection*, Ellicott City, MD, 1995, http://www.cwp.org/SPSP/TOC.htm.
- ❖ Lisa Austin, Washington State Department of Ecology Water Quality Program, *Stormwater Management Manual for Western Washington* (Publication 99-12), September 2001, http://www.ecy.wa.gov/pubs/9912.pdf.

- ❖ Betty Rushton, Southwest Florida Water Management District, *Low Impact Parking Lot Design Reduces Runoff and Pollutant Loads: Annual Report # 1,* Brooksville, Florida, 1999.

1.3.6 Devise landscape plans to limit water and energy demand while preserving or enhancing the natural environment.

A Formulate a plan to restore or enhance natural vegetation that is cleared during development. Within this plan, phase landscaping to ensure denuded areas are quickly vegetated.

B Select turf grass and other vegetation that are native or regionally appropriate species.

C Limit turf areas of landscaped area, selecting native and regionally appropriate trees and vegetation in a way that complements the natural setting.

D Group plants with similar watering needs (hydrozoning).

E Specify planting of trees to increase site shading and moderate temperatures (see also Energy Efficiency guideline 3.4.1.c specifying siting of trees to reduce the energy consumption of the home).

F Design vegetative wind breaks or channels as appropriate to local conditions.

G Require onsite tree trimmings or waste of regionally appropriate trees to be used as protective mulch during construction or as a base for walking trails.

H Establish an integrated pest management plan to minimize chemical use in pesticides and fertilizers.

Intent:

Landscaping water use accounts for approximately 50% of a home's total water needs. Conservation of this valuable resource through such techniques as hydrozoning, reducing turf area, and selecting regionally appropriate plants is a key component to responsible building. Thoughtful selection and placement of plants can also reduce heating/cooling loads of a home, provide habitat for native fauna, and minimize the heat-island effect of developments.

Additional Information / How to Implement:

Select landscaping materials and vegetation to fit site conditions. Regionally appropriate plants are hardy plants that can withstand local water and temperature conditions such as freeze, heat, drought, and rain. Regionally appropriate plants will also not be overly prolific or invasive, and will be able to coexist with other native plants over time.

Other benefits of landscaping with native plants: minimizes maintenance (reduces emissions of equipment); fosters wildlife habitat. See EPA's Mid-Atlantic Region Green Landscaping http://www.epa.gov/reg3esd1/garden/what.htm for more information.

When planning for the revegetation of a site, consider the multiple services that natural areas can provide: natural habitat, storm water processing, shading, wind break, etc. Trees that shade the streets can keep a neighborhood cool while also increasing the neighborhood's attractiveness. Properly selected plants can be grouped to serve as a bioretention zone. Deciduous trees allow the sun's rays through in winter and provide shade in the summer. Evergreens can provide an effective windbreak. Careful selection and integration of trees and vegetation can reduce a developer's initial costs while providing value to a development/neighborhood later. When planting trees, several factors should be taken into account such as the value of shading (trees shading asphalt will mitigate a site's temperature more than trees shading landscaped areas), maintaining a safe distance from the house (especially in areas prone to natural disasters), ultimate tree size, etc.

Developers may wish to consider enforcing guidelines for the protection of onsite vegetation. Some developers even fine builders for damage to areas designated for protection.

If grinding and scattering cleared plants, care should be taken to grind only regionally appropriate plants. Grinding of invasive species can increase their propagation and result in the ultimate destruction of native species.

One of the best ways to reduce energy consumption is through passive solar design of a home – using orientation, overhangs, fenestration, etc. Landscaping to reduce energy consumption is only part of the whole effort.

It is good practice to limit ratio of turf area to total landscaped area due to maintenance requirements of turf versus native plants and regionally appropriate trees and vegetation. In some areas, there may be restrictions on the percentage of turf that the front yard must contain. Research has shown that homeowners are comfortable with having as little as 50% of the front yard composed of turf. Fewer regulations are imposed on turf-to-landscaping ratio in the backyard, so good gains might be made more easily there. For research on turf and landscape of front yard with native species, see: Nassauer, Joan. 1995. *Messy Ecosystems, Orderly Frames.* Landscape Journal, 14 (2), 161-170.

In areas with low annual rainfall, one way to account for water usage is through the development and implementation of a water budget. Below is Built Green Colorado's Water Budgeting information.

Water Budgeting

Description

Calculate the water needs of irrigated landscapes based on plant types, land area and irrigation system efficiency. Use the calculated water budget to apply water according to the needs of the plants and manage irrigation. Overall property water budgets can be developed to include both indoor and outdoor water requirements.

Basic Practice Guidelines

A. The landscape design process should incorporate a general outdoor annual water budget to be used as a guideline for irrigation design and long-term landscape management. The water budget should be developed by the landscape architect or designer as part of the plant selection and grouping process (turf, trees, shrubs, ground covers, etc.).

B. The irrigation maintenance process should be based on calculation of a monthly and annual water budget for existing sites.

C. Calculate the site landscape water budget by summing the water requirements calculated for each hydrozone of the landscape using either of these general formulas:

Approach #1, when Reference ET is known:

$$\text{Water Budget} = \frac{(ET_o)(K_c)(LA)(0.623)}{IE}$$

Where:

Water Budget = Water Needed for Plants (gallons per year)
ET_o = Reference evapotranspiration (inches per year) for bluegrass in your area
K_c = Crop coefficient for plant type (See Appendix E for more information.)
LA = Landscaped Area (square feet)
0.623 = Conversion Factor (to gallons per square foot)
IE = Irrigation Efficiency (varies based on irrigation system)

Approach #2, when Reference ET is not known:

Water Budget = Land Area (sq. ft.) x Estimated Plant Water Use (gallons/sq. ft.)

Where:

Estimated Plant Water Use = Estimated water use in gallons/sq. ft. for the metro-Denver Front

Example Using Both Water Budgeting Approaches:

For purposes of a simple example, assume that 70% of a 5,000 sq. ft. of a northern Front Range landscape is Kentucky bluegrass irrigated with a properly designed automatic irrigation system with an 80% irrigation efficiency reported by the irrigation contractor. The remaining 30% of the landscape is "low to very low" water use plants irrigated with a drip irrigation system with a 90% irrigation efficiency reported by the irrigation contractor. The seasonal reference ET value for this northern Front Range location is 26.69 inches for cool season grass mowed at 5 inches. For the turf area, a crop coefficient (Kc) of 0.9 is applied to represent a nice quality Kentucky bluegrass lawn mowed at a 3-inch height. The "low to very low" water use plants require about 25% of reference ET, so the resulting water budget for the landscape would be:

Water for Turf Area = [(26.69"*0.9)*3500 sq.ft.*0.623]/0.8= 65,472 gal/yr

+ Water for Other Area = [(26.69"*0.25)*1500 sq.ft.*0.623]/0.9 = 6,928 gal/yr

Total Landscape Water Requirement = 72,400 gal/yr

This example results in an average water requirement of about 14.5 gallons/sq. ft. of irrigated area.

Using Approach #2, one would assume the 3,500 sq. ft. of bluegrass would use about 18-20 gal/sq. ft./yr and the 1,500 sq. ft. of low water plants would require about 5 gal/sq. ft., resulting in the following calculation:

19 gal/sq. ft. * 3,500 sq. ft. = 66,500 gal/yr
+ 5 gal/sq. ft. * 1,500 sq. ft. = 7,500 gal/yr

Total Landscape Water Requirement = 74,000 gal/yr, or about 14.8 gallons/sq. ft. of irrigated area.

Range area. For other areas, water use estimates may need to be increased or decreased based on climate and location characteristics. Water use estimates may also be reduced when more efficient irrigation systems such as drip irrigation are used.

D. The water budget provides the annual irrigation that the site needs in order to thrive in addition to natural precipitation. The annual water budget assumes a normal year of natural precipitation (14 inches of annual precipitation for the Front Range area). In either wetter or drier years, the water budget will need to be adjusted.

E. The rate at which plants lose water to the surrounding air is called evapotranspiration (ET). Temperature, humidity, wind and light all influence the ET rate. When watering, it is only necessary to replace the amount of water that has been lost due to ET.

F. In order for water budgets to be accurate, it is necessary to provide accurate information on factors such as crop coefficients. See the GreenCO web site (www.greenco.org) and Appendix E for recommended crop coefficients to be used in calculating water budgets.

G. It should be noted that the ET_0 (reference ET) in the water budget equation does not reflect that Kentucky bluegrass can be attractive and viable at much lower ET rates and can be very drought tolerant. For properly established turf, the actual irrigation water needs of turf can vary, depending on desired appearance.

H. The water budget does not apply to the initial establishment period for plantings, which can vary from 2-4 weeks for annuals to several growing seasons, depending on plant type and the timing of planting. One year is typical for many perennials and shrubs to become established.

I. Water features, outdoor pool(s), and/or any other outdoor water uses should be included in the water budget.

J. If a property manager/landscaper knows the water budget for each month, he/she can compare actual use to the site water budget and adjust irrigation practices accordingly. Excessive water use may also be attributed to irrigation system deficiencies, which should be corrected.

K. Evapotranspiration (ET) or "smart" irrigation controllers can facilitate landscape irrigation according to the needs of the plants (and therefore the water budget).

1. Low water-use plants don't automatically save water (they are easily and, frequently, over-watered). Using a "smart" controller can insure the proper irrigation is applied to low water-use plants.
2. High water-use plants (such as turf) don't automatically waste water. They are also often over-watered. Using a "smart" controller can insure the proper irrigation is applied to high water-use plants.

L. Often the retrofitting of poor irrigation systems and the use of "smart" controllers will provide a payback in saved water. To calculate the payback time, use the water budget to measure how much water is actually needed, versus how much has historically been used, along with local water rates and irrigation system cost.

M. GreenCO provides a simple water budget calculator on its Website at www.greenco.org. Green Industry professionals can use this calculator with customers to demonstrate that water budgeting is a manageable approach to understanding water needs for a given property and adjusting watering practices accordingly.

Regional or Industry Considerations/Adaptations

A. Water budgets can be used by water utilities to determine how much water is needed versus how much the utility sells or has.

B. Water budgets can be used by water utilities to determine how much water they need versus how much they sell or have. The difference is how much water could be saved, or how much more water needs to be purchased.

C. Water budgeting approaches adopted by utilities typically include ET-based irrigation scheduling combined with tiered pricing for increasing water usage. Tiered pricing, by gradually increasing the price of water as consumption rises, provides incentive to conserve. At the time of this manual's publication, this approach had been adopted in other water-limited states such as California and Arizona. See Centennial Water and Sanitation District in Highlands Ranch, Colorado, for information on their program http://www.highlandsranch.org/6/6-1a.html.

D. Colorado's Water Efficient Landscape Design Model Ordinance (see www.dola.state.co.us/smartgrowth/) is based on water-budgeting with a goal of 15 gallons/square foot/year of water required for a landscaped area.

E. Check the GreenCO Website (www.greenco.org) for more information on water budgeting techniques.

Key References

Ash, T. 1998. *Landscape Management for Water Savings How to Profit from a Water-Efficient Future.* Orange County, CA: Municipal Water District of Orange County.

California Department of Water Resources. 1993. Model Water Efficient Landscape Ordinance. Website: http://www.owue.water.ca.gov/landscape/ord/ord.cfm.

Centennial Water and Sanitation District. 2004. Water Conservation Program. http://www.highlandsranch.org/06_wsan/06_3watercons.html. Highlands Ranch, CO: Centennial Water and Sanitation District.

Colorado Department of Local Affairs. 2004. *Water Efficient Landscape Design Model Ordinance.* Website: www.dola.state.co.us/smartgrowth/. Denver, CO: Colorado Department of Local Affairs, Office of Smart Growth.

Colorado State University Cooperative Extension Drought Task Force. 2004. Website: www.drought.colostate.edu/.

Design Studios West, Inc.; J.M. Knopf; HydroSystems KDI, Inc.; The Restoration Group, Inc.; and G. A. White. 2004. *WaterWise Landscaping Best*

Practice Manual: A Companion Guide to Water Efficient Landscape Design. Website: www.dola.state.co.us/smartgrowth/. Denver, CO: Colorado Department of Local Affairs, Office of Smart Growth.

GreenCO. 2004. Water Budget Calculator at www.greenco.org.

McStain Neighborhoods. 2003. *Water Conservation Standards for Common Areas and Open Space Landscapes.* Boulder, CO: McStain Neighborhoods.

Mecham, B. 2004. *Scheduling Methods* Using ET as a Management Tool. http://www.ncwcd.org/ims/ims_info/scheduli.pdf. Loveland, CO: Northern Colorado Water Conservancy District.

Northern Colorado Water Conservancy District. 2004. Turfgrass Irrigation Management Program. http://www.ncwcd.org/ims/scheduler.asp. Loveland, CO: Northern Colorado Water Conservancy District.

Slack, E. 2001. Case History: Irrigation on a Water Budget, *Irrigation Business and Technology*, March/April. (www.irrigation.org).

Resources:

- Center for Plant Conservation, http://www.mobot.org/CPC/.
- Lady Bird Johnson Wildflower Center, Native Plant Information Network National Suppliers Directory, http://www.wildflower2.org/NPIN/Suppliers/suppliers.html.
- New England Wildflower Society, Native Plant Societies of the United States and Canada, http://www.newfs.org/nps.htm.
- NAHB Research Center Inc., *Onsite Grinding of Residential Construction Debris: The Indiana Grinder Pilot*, February 1999.

1.3.7 Maintain wildlife habitat.

Intent:

As the frontier of home building continues to expand, sharing the land with wildlife becomes an increasing challenge to builders. Through individual initiative or participation in a wildlife conservation program, home builders can work to create a habitat where both wildlife and humans can thrive - whether in an urban, suburban, or rural setting.

Additional Information / How to Implement:

(Extra points) Participate in a wildlife conservation program.

Examples of programs: USDA National Resources Conservation Service's Backyard Conservation Plan, the Audubon Cooperative Sanctuary System's Treasuring Home Initiative, or the National Wildlife Federation's Backyard Wildlife Habitat Program.

Enhance quality of habitat, including food sources, diversity of habitat, and protective areas, through selective plantings and site design.

Leave snags (dead tree or portion that's left for habitat). Provide bird houses.

Resources:

- Audubon International, *Audubon Cooperative Sanctuary System,* http://www.audubonintl.org/programs/acss/. Audubon Cooperative Sanctuary System's Treasuring Home Initiative.
- Become a certified participant in the National Wildlife Federation's Backyard Wildlife Habitat Program. https://secure.nwf.org/backyardwildlifehabitat/certify/page1.cfm.

1.4 Develop the site.

Minimize environmental intrusion during onsite construction.

1.4.1 Provide onsite supervision and coordination during clearing, grading, trenching, paving, and installation of utilities to ensure that targeted green development practices are implemented (see 1.3.4).

Intent:

The noblest intentions when designing a site are practically achieved through onsite supervision during the lot development phase. A qualified member(s) of the builder's team should be onsite as these activities progress to ensure that each objective is achieved according to targeted green lot specifications.

Additional Information / How to Implement:

The information for this line item should link to the plans and any documents produced in line item 1.3.4.

Resources:

Information will be added in Version 2.

1.4.2 Conserve existing onsite vegetation.

A. Minimize disturbance of and damage to trees and other vegetation designated for protection through installation of fencing and avoidance of trenching, significant changes in grade, and compaction of soil and critical root zones.

B. Prepare designated existing trees and vegetation for the impacts of construction through pruning, root pruning, fertilizing, and watering.

Intent:

After a builder has identified (during the planning stage) the existing vegetation that will be conserved onsite, practical steps must be taken during the development stage to achieve the intended conservation. Such steps include pre-development preparation of the vegetation and protection of the foliage, soil, and root system of designated vegetation.

Additional Information / How to Implement:

See Resources section.

Resources:

- National Arbor Foundation, *Building With Trees*, http://www.arborday.org/programs/Buildingwithtrees/index.cfm.

- Phillip A. Pratt and Michael W. Schnelle, Oklahoma State University, Oklahoma Cooperative Extension Service, *Site Disturbance and Tree Decline* (OSU Extension Facts F-6429), September 2003, http://osuextra.com/pdfs/F-6429web.pdf.

1.4.3 Minimize onsite soil disturbance and erosion.

A. Demarcate limits of clearing and grading.

B. Create construction "no disturbance" zones using fencing or flagging to protect vegetation and sensitive areas from construction vehicles, material storage, and washout.

C. Install and maintain sediment and erosion controls.

D. Stockpile and cover good soil for later use.

E. Reduce soil compaction from construction equipment by laying mulch, chipped wood, or plywood sheets.

F. Stabilize disturbed areas within 14-day period recommended by the EPA.

G. Improve the soil with organic amendments and mulch.

Intent:

This guideline seeks to ensure the field implementation of conservation plans. Each measure identifies a practical way to foster water quality and conserve onsite ecological habitat through reducing soil disturbance and erosion.

Additional Information / How to Implement:

Soil stabilization may be temporary or permanent.

Keep in mind that, while the use of stockpiled onsite soil is a preferred method, excavation, stockpiling, grinding, and screening destroy the ecological microsystem of the soil. Rejuvenation of the unimproved soil to its original form will take several years. To offset this phenomenon, the incorporation of compost and sand is an effective method for more rapidly rebuilding the structure and ecosystem of the topsoil and allowing turf and plants to establish more quickly. As indicated above, compost is recommended for this purpose.

When additional soil must be brought in, there are environmental advantages of using industrial by-products as ingredients in topsoil including foundry sand, biosolids compost, and other EPA-approved by-products. In addition to keeping these materials out of community landfills, processing techniques produce superior topsoil.

The use of organic mulch is an excellent way to conserve water in landscape beds and build soil quality. Ideally, use mulch that results from onsite recycling efforts such as yard waste, processed pallets, and other clean wood from construction waste.

Resources:

- King County Department of Natural Resources, King County, *Washington Surface Water Design Manual Appendix D: Erosion and Sediment Control Standards* (Seattle: September 1998), ftp://ftp.metrokc.gov/ddes/acrobat/esa/kcswdm-d.pdf.

1.5 Innovative options

Seek to obtain waivers or variances from local development regulations to enhance green building.

1.5.1 Share driveways or parking.

Intent:

Sharing driveways or parking can reduce the amount of impervious material on a lot, thereby decreasing storm water and pollution run-off.

Additional Information / How to Implement:

Information will be added in Version 2.

Resources:

Information will be added in Version 2.

1.5.2 Other (specify).

Information will be added in Version 2.

SECTION 2
RESOURCE EFFICIENCY

(A note regarding defining "low maintenance" materials: For certain types of building products, the buyer could be on the lookout for materials that have below average maintenance needs compared to other products in that same material category (e.g., composite decking or treated lumber). Although existing green builder programs provide good information for builders to emphasize the long-term advantages and savings of more durable, lower-maintenance products, there is currently no standardized method to assess the durability of residential construction materials or systems or to define "low maintenance." A possible approach that green home building program administrators can use at this time in is to give credit for extended warranties on materials and workmanship. The person choosing the building product should consider using manufacturer claims, warranty duration, third-party certifications and sources such as *GreenSpec Directory*, and Life-Cycle Assessment (LCA) tools that are under development as proxies to identify "low maintenance" or "durable" materials during the purchasing process.)

2.1 Reduce quantity of materials and waste

2.1.1. Create an efficient home floor plan that maintains a home's functionality

Intent:

Use the local data regarding the average size of homes built (taking bedrooms into account) and get credit for building a home with the same number of bedrooms but with fewer square feet than an average sized house.

Size homes, rooms, and wall heights based on available material sizes. Two-foot modules work well for floor plans. Wall height should be based on availability of structural framing members in pre-cut lengths (i.e., precut stud lengths).

Use designs that incorporate efficient mechanical systems layout, like stacked "wet walls" for efficient plumbing layout, minimized pipe runs, and rapid hot water delivery. Dedicate one "wet wall" per floor, i.e., kitchen sink and powder room or master and guest baths with back-to-back layouts that share a plumbing wall. Locate walls that contain drain/waste/vent and supply pipes on interior walls. (Section 5.3.5, *Indoor Environmental Quality*, also covers the design practice of installing water supply lines on interior walls.)

When homes require forced air space conditioning incorporate the HVAC duct layout in the architectural plan and design the ducts into the conditioned space of the building to maximize system efficiency.

Additional Information / How to Implement:

National data (from NAHB Research Center survey data) regarding average size of homes:

- 2 BR = 1,382 sq. ft.
- 3 BR = 1,890 sq. ft.
- 4 BR = 2,648 sq. ft.
- 5+ BR = 3,424 sq. ft.

In the table below you will note that the square footage of a 2 BR house must be reduced by 50 square feet in order to obtain an additional point. In order to determine how much the homes with 3, 4, and 5+ bedrooms must be reduced, we referenced the national data (see above). The average 3 BR house is 37% larger than the average 2 BR; the average 4 BR is 40% larger than the average 3 BR; the average 5+ BR home is 29% larger than the average 4 BR. These percentages were used in the table below to determine the house size thresholds.

For example,

- a 1,825 sf. home is 37% larger than a 1,332 sf. home;
- a 2,555 sf. home is 40% larger than a 1,825 sf. home;
- a 3,296 sf. home is 29% larger than a 2,555 sf. home.

Guidelines for Efficient Floor Plan Design

	# of Bedrooms				
Area of Home (Square Feet) (based on ANSI Z765-2003)	**2**	**3**	**4**	**5+**	**Points**
	1382	1890	2648	3424	0
	1332	1825	2555	3296	1
	1282	1756	2459	3172	2
	1232	1688	2363	3048	3
	1182	1619	2267	2925	4
	1132	1551	2171	2801	5
	1082	1482	2075	2677	6
	1032	1414	1979	2553	7
	982	1345	1883	2430	8
	932	1277	1788	2306	9

Resources:

- ❖ Use the newly-modified American National Standards Institute (ANSI) Z765-2003 to calculate square footage. Available from the NAHB Research Center Bookstore - http://www.nahbrc.org/tertiaryR.asp?TrackID=&CategoryID=1652&DocumentID=2636
- ❖ Oikos®, *Small, Efficient and Beautiful*, 17 Space Design Tips. http://oikos.com/esb/52/smallefficient.html
- ❖ There are many resources available to help a builder create efficient home floor plans. For example, Sarah Susanka's *Not So Big House* series of books can assist in home design. *The Not So Big House* (The Taunton Press, 1998); *Creating the Not So Big House* (The Taunton Press, 2000).
- ❖ GreenBuilder, *Sustainable Building Sourcebook,* http://www.greenbuilder.com/sourcebook/

- ❖ Environmental Building News and BuildingGreen.com, *GreenSpec Directory* http://www.greensage.com/BOOKS/GreenSpecs.html

2.1.2. Use advanced framing techniques that reduce the amount of material used to build a home while maintaining the structural integrity of the home.

Intent:

Advanced Framing or Optimum Value Engineering refer to framing techniques that reduce the amount of materials used to build a home while maintaining the structural integrity of the home. An optimum value engineered assembly tends to use less energy for space conditioning because the omitted (and redundant) structural components can be displaced with insulation. Accordingly, the user will note that some advanced framing techniques receive points for both *Resource Efficiency and Energy Efficiency.*

Additional Information / How to Implement:

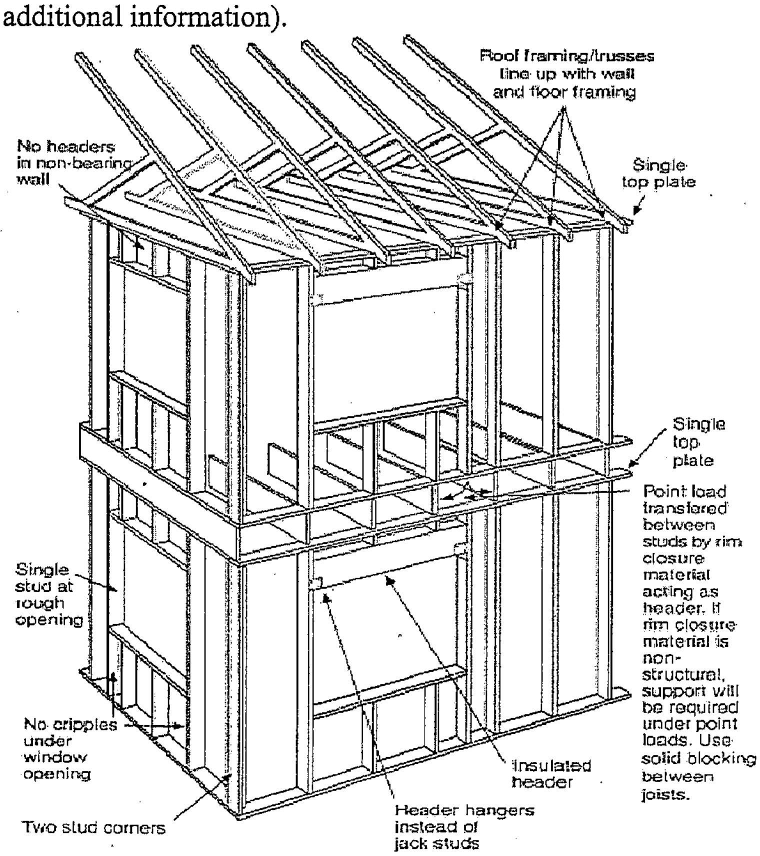
Advanced framing elements can be applied independently, or adopted in the entirety, depending upon the specific requirement(s) of the project. Framers unfamiliar with the techniques may need training, and the initial use of these techniques may temporarily slow down framing operations. In general, more planning is needed to implement these elements.

In addition to the advanced framing techniques described below for wood, homes with steel framing can incorporate similar techniques using advanced framing techniques, including 24" o.c. spacing for steel floors and walls, described in the HUDUSER's *Prescriptive Method for Residential Cold-Formed Steel Framing* (see Resources section of this line item for additional information).

Some of the benefits of advanced framing include:

- ❖ Reduced first cost (3 to 5% of framing cost)
- ❖ Improved energy efficiency (2 to 5% per year)
- ❖ Improved resource efficiency (less wood consumption and waste)

Advanced framing uses engineering principles to minimize material usage while meeting model building code structural performance requirements.



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The following list covers different principles that form an advanced framing system:

- 19.2" or 24" on-center framing, floor systems
- 19.2" or 24" on-center framing, bearing walls
- 24" on-center framing, roof systems
- 24" on-center interior partitions
- Single top plate walls
- Right-sized headers or insulated (box) headers (where required)
- Eliminate headers in non-bearing walls
- Doubling the rim joist in lieu of header (2x6 or deeper wall framing)
- Ladders blocking at interior-wall-to-exterior-wall intersections
- Two stud corner framing

Builders need to employ at least two of the items above in order to get 4 points for this line item. An additional point may be added for each additional technique employed to a maximum of eight points.

19.2" and 24" ON-CENTER FRAMING

Details: Wall and floor framing spacing can often be engineered for 19.2" (1/5 of an 8-foot sheet) or 24" on center (1/4 of an 8-foot sheet). Roof framing that utilizes trusses is most frequently spaced at 24". This strategy can be combined with *modular layout and single top plate* for added economy, but can also be used independently

Installation: Installation should be in accordance with manufacturer's specifications and model building code prescriptive methods. Bracing and fastening schedules and sheathing thickness requirements increase with framing spacing.

Careful spacing of window and door openings will maximize the economy of wider spacing. Designs that are built repeatedly should include wall framing layout drawings to guide the framing crew. When first implementing advanced framing elements, crews are likely to be slowed down until they become more familiar with the method.

Benefits/Costs: Approximately one-third of the lumber can be eliminated from the wall and floor framing of a value-engineered house, over walls and floors spaced 16 inches on center. Floor joists may need to be deeper for wider spans, but the reduction in lumber required for the building usually offsets the price increase from having larger floor joists. The need for thicker deck sheathing will also offset a portion of the savings. A careful analysis or a trial prototype is needed to determine whether the wider spans make economic sense for a particular plan. In general, simpler plans designed on a two-foot module are much more likely to result in savings with 24" on center framing than are complex plans with odd dimensions and many small offsets. However, resource savings will occur regardless of economic savings.

Wider stud spacing contributes to energy efficiency by reducing the amount of lumber in a wall cavity. Since more insulation and less lumber is used, and since insulation has a higher R-value than lumber, increasing stud spacing increases the overall R-value of the wall system. Limitations: Floor decking, wall cladding, roof sheathing and interior finish material (such as gypsum wall board) need to be sized to span the added dimension without undesirable deflection. If floor joists are chosen that have wide flanges, this will reduce the clear span of the floor decking. Material fastening schedules and sheathing thicknesses become more stringent when wider spans are employed, which may affect quantities, installation time, and cost of accessories.

One-half-inch thick gypsum board will deflect somewhat more over 24" framing than 16" framing, although it is commonly used. An alternative would be to use half-inch "anti-sag" or 5/8" gypsum board.

Some manufacturers do not make insulation batts for 19.2" on center framing. Therefore, using this spacing in an insulated wall assembly may require changing type or brand of insulation.

In some markets, there is a perception that wide-spaced framing is a mark of inferior construction. Attention to all of the details of assembly, including fastening and bracing schedules, will assure that the system performs well.

Code/Regulatory: Model codes allow bearing walls framed with 2x4 studs spaced 24" on center or single top plates on bearing walls within defined structural guidelines. Designs in high-wind zones or with tall walls may not allow 24 inch on-center spacing.

SINGLE TOP PLATE - EXTERIOR AND BEARING WALLS

Details: Single top plates are typically incorporated with advanced framing designs that include 24" on center framing. By stacking the wall and roof framing, it is possible to use a single top plate because the top plate merely transfers compressive vertical loads to the stud below. Steel plates or straps are used to maintain continuity of the plate in the absence of a second, overlapping plate.

Installation: Temporary bracing is needed to steady and plumb newly erected walls. As with all light frame structures, temporary bracing should be left in place until the floor and, or roof is completed to permanently brace the structure.

Benefits/Costs: In a 28' x 40' two-story house, the savings by eliminating second top plates in bearing and non-bearing walls is equivalent to eliminating about 35 studs. Because one plate is omitted, the amount of wall insulation is increased, slightly improving energy performance.

Limitations: May not work on homes in high-wind or earthquake zones. Requires purchasing a longer stud.

Code/Regulatory: Meets model codes in some designs, but is more likely than other OVE practices to raise questions from building officials.

SINGLE TOP PLATE - INTERIOR NON-BEARING PARTITIONS

Details: Any non-bearing partition can be built with a single top plate.

Installation: Bracing is needed to steady and plumb recently erected walls. This bracing should be left in place until the floor or roof above the walls is completed, tying the structure together.

Benefits/Costs: Savings depend on the design's linear feet of non-bearing walls. In a 2,200 sq. ft. home, the equivalent of 2 or 3 dozen studs are likely to be saved on interior walls.

Limitations: If used along with a normal double plate on bearing and exterior walls, two lengths of wall studs are required on the job, which could be confusing.

Code/Regulatory: Meets codes, but is more likely than other OVE techniques to inspire questions from the building official.

RIGHT-SIZED HEADERS or INSULATED BOX HEADERS

Details: Instead of sizing all headers in bearing walls to accommodate the greatest load case, size each header for its actual load and span using the appropriate wood species. Also consider the benefit of using a deeper, single-ply, and engineered wood header.

If the tedium of framing different header depths to uniform head heights at openings is daunting, use insulated box headers that facilitate load transfer above openings and use fewer resources than 2-ply solid sawn members. Typically, a boxed header design consists of a top and bottom 2x4 on the flat, some end and interior cripples and a plywood face on one or two sides. The hollows in the header interior allow insulation to be added.

Installation: Headers of various sizes require framers to pay attention to plans and customize openings. An alternative would be to site-fabricate and insulate box headers of a consistent depth and install these in lieu of dimensional or engineered wood headers.

Benefits/Costs: Material cost and usage economies must be balanced against the chance of installing the wrong sized header and slowing down the framing process by making opening head framing inconsistent. Similarly, material economies associated with fabricating box headers of consistent depth will be offset by labor involved with fabricating these on site. The need to have an additional material, insulation, on hand at the rough frame stage makes the bill of materials more complex.

Reducing the use of large-dimensioned lumber is environmentally desirable.

Limitations: Without thoughtful implementation, right sizing headers could result in uneven window and door head heights. The practice requires cutting different sized cripples over headers.

Code/Regulatory: Model building codes include prescriptive methods for sizing headers and girders, as well as sizing and constructing box headers.

NO HEADERS IN NON-BEARING PARTITIONS

Details: Although it is obvious that headers are not needed in non-bearing partitions, it is not always obvious which partitions are load bearing and which are not. Thus, framers often put headers over every opening to be safe. Eliminating these headers saves both material and labor.

Installation: If a method of identifying the bearing walls versus the non-bearing partitions is included on the plans, the layout framer can determine which openings need headers. For instance, solid blue walls can denote bearing and uncolored walls would be non bearing.

Benefits/Costs: Saves material and labor cost, and conserves resources by reducing the use of wide dimension lumber.

Limitations: None.

Code/Regulatory: Model codes do not prescribe headers in non-bearing locations, although it may be necessary to demonstrate to the inspector that a partition is non-bearing.

LADDERS AT PERPENDICULAR WALL INTERSECTIONS

Details: Use flat horizontal blocking between studs to secure a perpendicular wall rather than solid vertical framing. (With 24" on center wall framing, three 22-1/2" scrap pieces are set at 24" on center vertically to replace two studs.)

Installation: Cutting and nailing three pieces of blocking requires approximately the same labor as installing two studs.

Benefits/Costs: Less lumber is used, and scrap pieces can be used for blocking. The horizontal blocking stiffens the wall junction. Most important, insulation in the exterior wall can be installed continuously behind the ladder frame.

Limitations: Blocking should be set so that it does not conflict with light switches and outlets.

Code/Regulatory: The system has no impact on model codes.

TWO STUD EXTERIOR CORNER FRAMING

Details: Only two studs are needed at an outside building corner, one at the end of each intersecting wall end. Any additional framing is needed only to support the gypsum board at the inside corner. Gypsum can be supported either with a flat stud, to leave an open-ended cavity at the corner; or with drywall clips, thus eliminating the need for a third stud.

Installation: If using a third stud for gypsum board backing, the extra stud can be a 2x4, even if the wall is composed of 2x6 studs.

Benefits/Costs: With a two-stud corner, one stud is eliminated. In all cases, the open cavity at the corner can be insulated along with the wall, eliminating the need for the framer to insulate a closed cavity before the sheathing goes on.

Limitations: Drywall clips are unfamiliar to some builders and subcontractors. Exterior corner trim or cladding may result in being secured to the sheathing only and not to the stud.

Code/Regulatory: More studs may be required at corners in high-wind or earthquake zone construction.

Availability: Drywall clips are readily available.

DOUBLING THE RIM JOIST IN LIEU OF HEADER (2x6 or wider wall construction)

Details: In thick wall construction, 5 ½" or greater actual wall dimension, it is possible to have the floor system rim board act as the header, or one member of a 2-ply girder or header assembly, at the door or window openings located below that member.

Installation: The joists that frame into this structural member will be shorter than other joists if the design requires a two-ply member to carry the span across the opening. Multiple-member headers should be properly fastened to assure load sharing.

Benefits/Costs: Some labor may be saved in framing the header, but extra labor and thought is involved in fitting perpendicular joists inside the two-ply assembly and framing the opening height down. The concept works best for long spans where the extra depth of the member or additional height of the opening is needed. The design is also an efficient method for use above openings in foundations.

Limitations: If the rim joist is intended to act along with the extra member (or by itself), it must be continuous across the opening.

Code/Regulatory: This is an unusual technique and may inspire questions from the inspector.

Resources:

- NAHB Research Center, *Advanced Framing Techniques: Optimum Value Engineering,* http://www.nahbrc.org/tertiaryR.asp?TrackID=&DocumentID=2021&CategoryID=70.
- HUDUSER, *Prescriptive Method for Residential Cold-Formed Steel Framing,* http://www.huduser.org/publications/destech/pm2.html
- Building American, DOE, *Optimum Value Engineering Best Practices,* (September, 2002), http://www.ibacos.com/pubs/OptimumValueEngineering.pdf.
- DOE, *Advanced Framing for Walls and Ceilings,* http://www.energy.state.or.us/code/respub/res10.pdf
- International Code Conference, *2003 International Residential Code®*, Panel Box Headers, Table R602.7.2, pg. 123, and Fig. R602.7.2, pg. 124.

2.1.3. Use building dimensions and layouts that maximize the use of the resources without the need to cut materials.

Intent:

Use of standard or modular dimensions in layout will reduce waste by not having to cut materials.

Additional Information / How to Implement:

Modular dimensioning was adopted in the late 1960s and is widely used. Adherence to modular dimensioning can reduce waste of material on the job site.

- One side of a door and window opening located at regular 16" or 24" stud positions.
- Modular window sizes used, with both side studs located at normal 16" or 24" stud positions.
- Building dimension in the direction parallel to the primary joist span is evenly divisible by 4 feet.

- Building dimension in the direction perpendicular to the primary joist span is evenly divisible by 2 feet.

Building to a 2' module and using 24" on-center wall and floor framing will maximize framing material resource efficiency and cost savings. Few homes can be entirely confined to a rigid module because typical dimensions such as the width of a tub or corridor are not in two-foot modules. To maximize savings, window sizes, and placement should be coordinated with the two-foot module.

Resources:

NAHB Research Center, PATH technology list, *Advanced Framing Techniques: Optimum Value Engineering (OVE)*,

http://www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2021&CategoryID=70

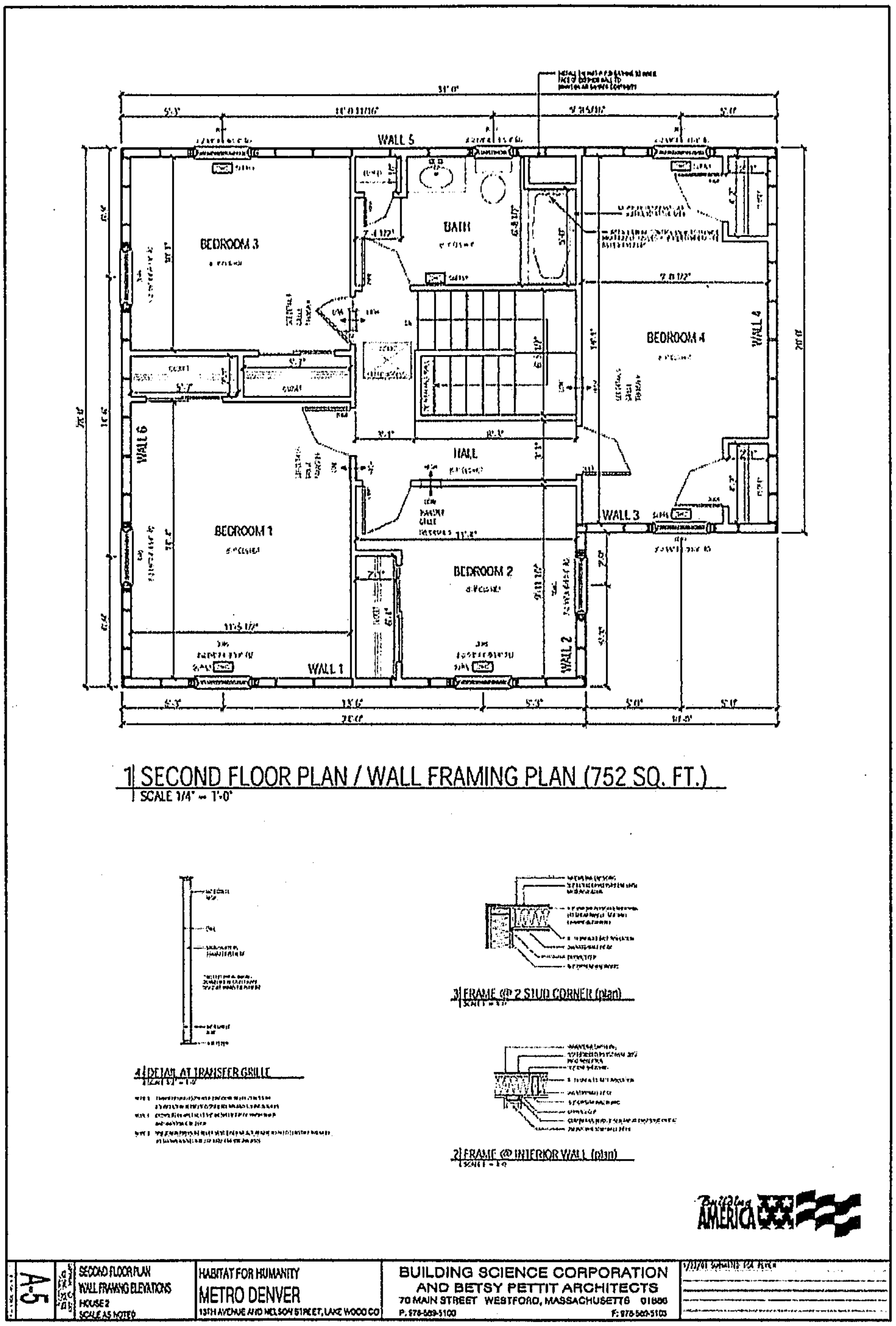
2.1.4 Create a detailed framing plan and detailed material takeoffs. Provide an onsite cut list for all framing and sheathing material.

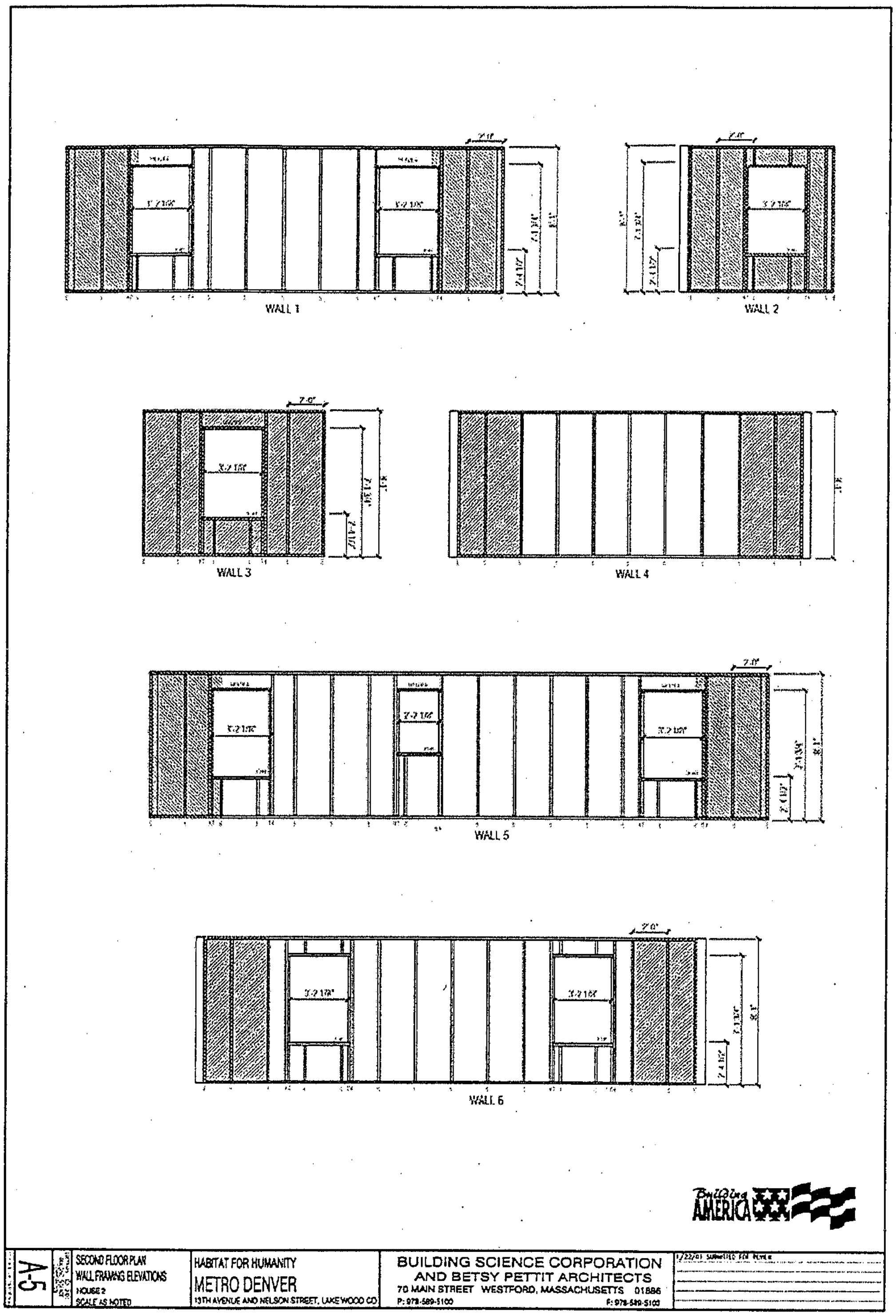
Intent:

Recognize the benefits of careful planning in the design, purchase, and installation phases. A framing plan provides a blueprint for the layout of each piece of lumber. A plan eliminates redundant (off-layout) studs at window openings or joists at stair and mechanical chase openings that can act as thermal bridges. The layout provides an accurate count for generating a bill of materials that reduces jobsite waste.

Additional Information / How to Implement:

A detailed framing plan can be as complex as a three dimensional perspective generated in a computer assisted design (CAD) program or as simple as a 1/8" scale drawing detailing the floor, wall, roof, lumber or component layout, dimensions for rough opening(s), headers and girders, and blocking locations. The following pages show examples of a wall framing plan using advanced framing techniques.


WALL 5
BEDROOM 3
BATH
BEDROOM 4
WALL 4
WALL 6
HALL
BEDROOM 1
BEDROOM 2
WALL 1
WALL 2
WALL 3
1 SECOND FLOOR PLAN / WALL FRAMING PLAN (752 SQ. FT.)
SCALE 1/4" = 1'-0"
3 FRAME @ 2 STUD CORNER (plan)
4 DETAIL AT TRANSFER GRILLE
2 FRAME @ INTERIOR WALL (plan)
A-5
SECOND FLOOR PLAN
WALL FRAMING ELEVATIONS
HOUSE 2
SCALE AS NOTED
HABITAT FOR HUMANITY
METRO DENVER
BUILDING SCIENCE CORPORATION
AND BETSY PETTIT ARCHITECTS
70 MAIN STREET WESTFORD, MASSACHUSETTS 01886


WALL 1
WALL 2
WALL 3
WALL 4
WALL 5
WALL 6
Building AMERICA
A-5
SECOND FLOOR PLAN
WALL FRAMING ELEVATIONS
HOUSE 2
SCALE AS NOTED
HABITAT FOR HUMANITY
METRO DENVER
13TH AVENUE AND NELSON STREET, LAKEWOOD CO
BUILDING SCIENCE CORPORATION
AND BETSY PETTIT ARCHITECTS
70 MAIN STREET WESTFORD, MASSACHUSETTS 01886

2.1.5. Use building materials that require no additional finish resources to complete application onsite.

Intent:

Materials that do not require additional finish resources save on priming, painting, and/or additional resources at the installation stage. Additionally, fewer resources are needed for recurring maintenance.

Additional Information / How to Implement:

Tip: Ask manufacturer or installer whether a product requires any additional finish.

Examples (not an exhaustive list):

- Pigmented and stamped concrete-surfaced interior floors (of a slab-on-grade foundation).
- Exterior trim not requiring paint or stain.
- Windows with finished surfaces not requiring paint or stain.
- Siding not requiring paint or stain.

Resources:

Information will be added in Version 2.

2.1.6 Use pre-cut or pre-assembled building systems or methods

A. Provide a pre-cut (joist) or pre-manufactured (truss) floor and roof framing package (points provided for a flooring or roof framing package – additional points provided if both packages are done)

B. Provide a panelized wall framing system

C. Provide a panelized roof system

D. Provide modular construction for the entire house

Intent:

Utilizing materials that do not require additional resources and/or onsite assembly optimizes plant manufacturing efficiencies and offers protection from the elements. Less time (site impact) and resources are spent onsite.

Additional Information / How to Implement:

For Option A, the builder would receive 3 points for using a flooring package, 3 points for a roof framing package, or 6 points for using both.

Precut material packages – A precut floor or roof package can be bundled and shipped for sequencing of use in layout and covered to minimize exposure to the elements. Pieces are marked by location on a layout plan that is provided on the blueprint or with the package. Package delivery can be scheduled for just-in-time delivery to minimize site disturbance. Not having to cut or calculate the position of the components of the floor system speeds assembly, eliminates onsite waste, and saves labor. Contractor-focused lumberyards and component manufacturers that supply engineered wood will have the resources to provide this value-added service. Another resource is building material supply dealers who supply steel stud framing packages.

Pre-manufactured component packages – Open-web floor or roof truss packages also benefit from the efficiencies listed above for precut material packages. Because building components can be engineered with 2x4 and 2x6 lumber to perform as capably as wide dimension lumber, components present an opportunity to reduce the resources in a home. Often, the reduced amount of board feet of lumber in the component facilitates easier handling because of the reduced weight.

Panelized construction – Open wall panels, manufactured in a factory, benefit from efficient purchasing and use of materials, automated cutting and fastening methods, and assembly in an environment that is protected from the elements. Panels are custom manufactured and delivered to meet the builder's schedule. A layout plan aids the carpenter in assembling the walls on site. Using panels can save several days in the critical path of assembly and speed the process of "closing-in" the home.

Modular construction – entire sections of the home are constructed and transported to the site. Modular housing goes further in reducing waste on site, since the unit is delivered to the site 70 to 85% finished. Modules are moved onto a site-built foundation, connected, repaired at common junctions, and tied in to utilities. Homes can be made ready for move-in within one week.

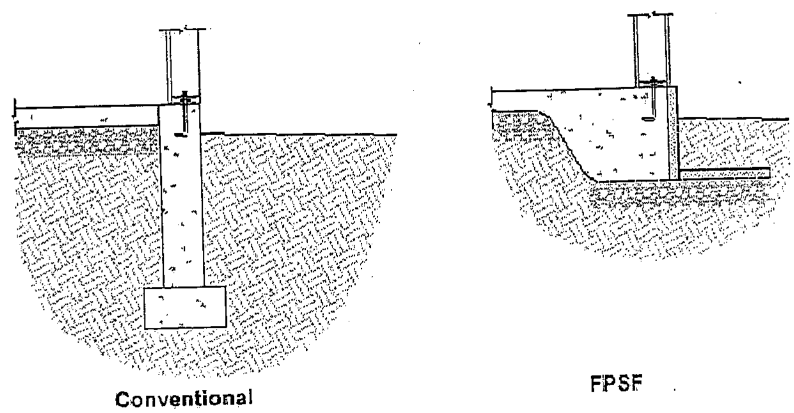
Resources:

- NAHB, Building Systems Council, *Fast Facts: Systems-Built Housing,* http://www.nahb.org/generic.aspx?sectionID=455&genericContentID=10216 and www.buildingsystems.org
- U.S. HUD, *Builders' Guide to Residential Steel Floors,* http:www.huduser.org/Publications/PDF/steelfloor.pdf

2.1.7. Install a frost-protected shallow foundation (FPSF).

Intent:

Minimize the excavation and site disturbance for foundations. Frost-protected shallow foundations use fewer materials than conventional foundations.



Sections of Conventional and Frost-protected Shallow Foundations.

A008537

Additional Information / How to Implement:

A FPSF incorporates strategically placed insulation to raise soil temperature and the frost depth around a building, thereby allowing foundation depths as shallow as 16 inches for almost all areas of the continental U.S. Model codes have recognized frost-protected shallow foundation design principles since 1995. Performance has been proven in European cold climates like Scandinavia, where FPSFs have been installed for the past 75 years.

Resources:

- NAHB Research Center, Revised Guide to Frost-Protected Shallow Foundations http://www.toolbase.org/docs/SubsystemNav/Foundations/4495_RevisedFPSFGuide.pdf

2.2 Enhance durability and reduce maintenance

Intent:

Building designs, material choices and installation techniques should seek to minimize the effects of degradation and weathering, enhance life expectancy of the assembly, and lessen maintenance needs.

Additional Information / How to Implement:

Durability may be defined as the ability of a material, product, or building to maintain its intended function for its intended life-expectancy with intended levels of maintenance in intended conditions of use.

Fortunately, many of the best practices intended to improve durability require little more than good judgment and a basic knowledge of the factors that affect building durability. A thorough review of resource publications will provide a solid foundation for addressing durability during the stages of construction.

Resources:

- NAHB Research Center for PATH, *Durability by Design*, http://www.huduser.org/publications/destech/durdesign.html
- Canadian Architect, *Measures of Sustainability*, http://www.cdnarchitect.com/asf/perspectives_sustainibility/measures_of_sustainablity/measures_of_sustainablity_durability.htm
- The Residential Moisture Management Network is working on addressing issues related to moisture management in homes, http://www.rmmn.org/
- Installation details for wood framed construction that will minimize moisture intrusion into the building envelope can be found at http://www.buildabetterhome.org. Publications on foundations, roofs and walls can be downloaded by going to each of those sections under the "builder tips" and then clicking on "get the brochure."

2.2.1 Provide a covered entry (e.g., awning, covered porch) at exterior doors to prevent water intrusion and subsequent rotting of joists, sills, and finishes.

Intent:

A roof over an entry to a home sheds precipitation and sunlight from the opening, protecting door finish and penetration of moisture around jambs, trim and threshold, thereby minimizing the need for maintenance of these areas. Roofs over entries are convenient for the occupant during foul weather and are an architectural feature that can enhance a home's visual appeal and provide an outdoor living space.

Additional Information / How to Implement:

Designs should include a roof or recessed front opening of a depth equal to or greater than the recommended roof overhang for the region.

Resources:

Information will be added in Version 2.

2.2.2. Use recommended-sized roof overhangs for the climate.

Intent:

Protect the building envelope and enhance the home's durability through the use of overhangs. Use overhangs to shade windows from summer heat gain.

Additional Information / How to Implement:

The following table presents the recommended roof eave and rake overhangs for the climate:

RECOMMENDED MINIMUM ROOF OVERHANG WIDTHS FOR ONE- AND TWO-STORY WOOD FRAME BUILDINGS*

Climate Index (see map below)	Eave Overhang (Inches)	Rake Overhang (Inches)
Less than 20	N/A	N/A
21 to 40	12	12
41 to 70	18	12
More than 70	24 or more	12 or more

Source: *Modification of Prevention and Control of Decay in Homes* by Arthur F. Verrall and Terry L. Amburgey, prepared for the U.S. Department of Agriculture and U.S. Department of Housing and Urban Development, Washington, DC, 1978.

* Table based on typical 2-story home with vinyl or similar lap siding. Larger overhangs should be considered for taller buildings or wall systems susceptible to water penetration and rot.

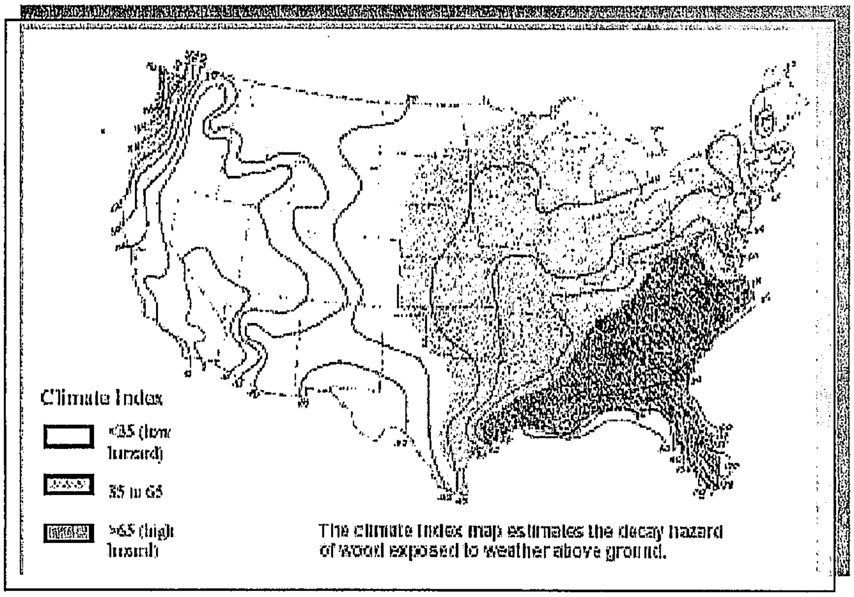
Resources:

NAHB Research Center for PATH, *Durability by Design*, http://www.huduser.org/publications/destech/durdesign.html

2.2.3. Install perimeter drain for all basement footings sloped to discharge to daylight, drywell, or sump pit.

Intent:

Divert surface and subsurface water away from the house and limit water seepage through the foundation walls and basement slab.



(Climate Index Map Based on Mean Monthly Temperature and Number of Rainy Days)

Additional Information / How to Implement:

A perimeter footing drain system of perforated pipe should be installed below the level of the basement slab on the inside and outside of the foundation wall and interconnected. Pipe should be wrapped with filter fabric and surrounded with a prescribed minimum of (IRC® 12" x 6", exterior) clean gravel or crushed stone. If the outfall is to a sump pit, and the pit requires mechanical removal, pipe should be installed for outfall 10' away from foundation wall that does not cause localized erosion.

Resources:

Information will be added in Version 2.

2.2.4. Install drip edge at eave and gable roof edges.

Intent:

The drip edge directs roof runoff water into the gutters and away from the fascia and roof sheathing.

Additional Information / How to Implement:

Drip edge is an inexpensive accessory that can be included in the roofer's scope of work and roofing material package.

Resources:

- Truini, Joseph, *This Old House*, Roof Runoff Remedy, http://www.thisoldhouse.com/toh/knowhow/solutions/article/0,16417,193154,00.html

2.2.5. Install gutter and downspout system to divert water at least 5' away from foundation and from there into the overall onsite drainage area.

Intent:

Moisture intrusion of foundations is avoided by moving runoff water beyond the foundation.

Additional Information / How to Implement:

Storm water can be diverted from the roof and into a rain garden. Such a technique can help beautify the yard, reduce the amount of mowing needed, and reduce the need to use potable water for watering.

Resources:

Information will be added in Version 2.

2.2.6 Divert surface water from all sides of building. Slope top of backfill to achieve settled slope of at least 6" of fall within 10 feet of the foundation walls.

Intent:

Moisture intrusion of foundations is avoided by moving runoff water beyond the foundation.

Additional Information / How to Implement:

Resources:

- Steven Winter Assoc., Inc. for HUD, *Volume 1 Rehab Guide: Foundations, Chapter 4*, http://www.toolbase.org/docs/SubsystemNav/Foundations/4406_rehab1_found.pdf

2.2.7. Install a continuous and physical foundation termite barrier in areas where subterranean termite infestation is locally problematic.

Intent:

Providing a non-chemical termite obstruction offers a long-term solution to termite infestation avoidance.

Additional Information / How to Implement:

IRC Fig. R 301.2(6) has a *Termite Infestation Probability Map* of the United States delineating the country into different zones of infestation levels; heavy, moderate-to-heavy, etc. The local HBA may offer information on the regional probability of termite infestation in consultation with local cooperative extension service and other termite experts.

Using a foundation termite shield is only one way a builder can effectively combat termite infestation. Following is a breakdown of the homebuilding process and a list of the tactics that can be used in an environmentally-aware fashion to accomplish termite resistance.

I. Site.

A. Selection - termites dislike dry conditions. Choose a site that is well-drained and ventilated.

B. Sanitation - the majority of termites that infest homes live underground and food (cellulose in the form of wood, paper, leaves, etc.) stored underground may lead termites to a house. When preparing a site for construction, don't bury vegetation and construction debris. After foundation construction, don't include wood scraps in the backfill.

C. Landscaping - Keep homes dry. Slope finish grade away from the house. Keep plantings well away from homes. Roots act as underground bridges through chemical or physical termite barriers. Plants such as shrubs and trees can prevent ventilation to the home and prevent drying after precipitation events.

II. Design

A. Layout - Keep houses dry. Ensure that wood elements are stopped at least 8" above finish grade. Termites can form hills or tubes that extend from the soil to food. Greater clearance between ground and wood elements prevents this situation and allows more time for detection should termites use tubes to reach above-ground food sources. Keep untreated wood away from contact with concrete. Concrete is a good conductor of water and untreated wood in contact with concrete may decay or attract termites.

B. Thermal - Termites love moisture and moisture comes from many sources. Proper design of the exterior envelope will prevent condensation from occurring.

C. Materials - Areas of the home that are particularly susceptible to moisture, like shower and bath surrounds should not be detailed with cellulose materials. Penetrations through the foundation, walls, and roof are all vulnerable to moisture intrusion and care should be taken to minimize these penetrations. To protect against foundation penetrations, consider using one of new physical barriers in the marketplace. Termiticides bonded between a polymer fabric and a stainless steel mesh small enough to keep out termites are some of the innovations available.

III. Construction Process

A. Material Storage - Keep moisture sensitive materials dry and don't incorporate compromised products into the house. Arrange to have materials delivered as close to the time of installation as practical.

B. Flashing - Penetrations through the exterior envelope are particularly vulnerable to moisture intrusion. Properly flash and seal all penetrations to prevent moisture accumulation.

IV. Post Construction

A. Owner Education - Inform homeowners about the value of dry homes and practices they can perform to keep the house free of termites and decay. Describe prevention features of the home and how these features can become compromised.

B. Termite Control - Should termites need subsequent control, consider targeted poisons such as baits.

Resources:

- Canadian Wood Council, *Termite Control and Wood-Frame Buildings: Slab and Foundation Details,* http://www.cwc.ca/publications/building_performance/termites/structural.php
- NAHB Research Center, *Termite Baiting* http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1402&DocumentID=2153
- University of Kentucky Entomology, *Termite Baits: A Guide for Homeowners,* http://www.uky.edu/Agriculture/Entomology/entfacts/struct/ef639.htm
- Termiticide fabric and mesh manufacturers, http://www.impasse.com/ and http://www.termi-mesh.com/

2.2.8. Use termite-resistant materials for walls, floor joists, trusses, exterior decks and other exterior wood in regions known to be termite infested.

Intent:

By eliminating the cellulose food source for termites or repelling termites, the home's durability is enhanced.

Additional Information / How to Implement:

Use the IRC® infestation map referenced in Section 2.2.7 to determine the probably of infestation for the region. Termite-resistant materials include naturally pest-resistant species of wood (e.g., redwood, cedar, white oak, black locust), treated wood (borate or ground contact solutions), masonry, steel, and concrete.

Reduce humidity in crawl spaces. Keep shrubs, vines, and other vegetation from growing over ventilation openings. Never bury wood scraps or waste lumber in the yard. Remove old tree stumps and roots around and beneath the building. Inform the homeowner to keep firewood piles away from the house, raised off the ground and covered.

Resources:

- Durable-Wood.com, Forintek Canada Corp., *Termite Control and Wood-Frame Buildings* http://durable-wood.com/termites/termitecontrol-e.pdf
- Western Wood Preservers Institute, http://www.wwpinstitute.org
- *Terminate the Termites*, www.steelframingalliance.com

2.2.9 Provide a weather resistive barrier (WRB) or a drainage plane system behind the exterior veneer system or the exterior siding.

Intent:

To protect the building envelope from water intrusion by installing a secondary, exterior-wall water management system.

Additional Information / How to Implement:

Wind-driven rain and air pressure differentials allow water intrusion into and behind most exterior claddings and veneers. A comprehensive approach to water management prevents water from reaching the sheathing or framing. Primary water management strategies include water-shedding architectural features including overhangs and exterior claddings. Secondary (redundant) water management to protect the sheathing and framing from moisture damage can be in the form of a weather-resistive barrier, a distinct drainage plane, or both.

As part of a whole-wall design, weather-resistive barriers need to be integrated with other wall system components, including structure, insulation, vapor retarder, air retarder (if separate), and flashing systems.

Resources:

- NAHB Research Center, *Weather-Resistive Barriers*, http://www.toolbase.org/docs/MainNav/MoistureandLeaks/3950_weatherresistantbarriers.pdf

2.2.10. Install ice flashing at roof's edge.

Intent: 

The eave edges of a roof are particularly susceptible to water intrusion from wind-driven rain, clogged gutter backup, and freeze-thaw cycles after winter snowfalls. Ice barrier or flashing is a redundant barrier that protects the sheathing near the roof edges, and keeps water out of the attic and walls.

Additional Information / How to Implement:

The IRC® requires that, in areas where the average daily temperature in January is 25°F or less, an ice barrier consisting of at least two layers of underlayment cemented together or a self-adhering polymer modified bitumen sheet, that extends from the edge of the eave to a point at least 24 inches inside the exterior wall line of the building, be installed. It is recommended that the ice barrier approach be used for green home construction. Because the redundant protection provided by an ice barrier protects against many weather phenomena – such as rain storms with high winds and winter snow, the practice is recommended for homes in most climates of the U.S.

Resources:

University of Minnesota Extension Service, *Ice Dams*,

http://www.extension.umn.edu/distribution/housingandclothing/DK1068.html

2.2.11 Install enhanced foundation waterproofing

Intent:

To keep moisture out of the foundation by providing a waterproof exterior coating or engineered exterior drainage plane.

Additional Information / How to Implement:

Foundation coatings that are required by the model building codes help prevent moisture from penetrating the foundation. A number of products are available to provide a more permanent barrier to moisture at the exterior of the foundation.

Resources:

ToolBase Services, *Foundation Drainage Panels,* http://www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2063&CategoryID=1010

2.2.12 Employ and show on plans the following flashing details:

- Around windows and doors,
- Valleys,
- Deck/house juncture,
- Roof/wall junctures, chimney step flashing, and
- Drip cap above windows and doors.

Intent:

To specify and call out the details of systems integration on the blueprints rather than leaving them to the half dozen or so specialists who perform installation of adjacent materials on the jobsite. All junctions of dissimilar material and flashing details are to be shown on plans.

Additional Information / How to Implement:

Product manufacturer's installation guides and association best practices details are good sources for the correct detailing of systems.

Resources:

Brick, http://www.gobrick.com/html/frmset_thnt.htm

Masonry products, www.ncma.org.

Various, http://pix.nrel.gov:8020/BASIS/nich/www/bapublic/SDF

Windows and doors, http://pix.nrel.gov:8020/BASIS/nich/www/bapublic/SDF

Wood, http://apacad.org/

EEBA Water Management Guide - http://www.eeba.org/mall/water.asp - This guide presents a variety of recommendations for minimizing water intrusion into homes. These recommendations are not intended to apply to every conceivable situation but are intended to illustrate principles.

2.3 Reuse materials

2.3.1 Disassemble existing buildings (deconstruction) instead of demolishing.

Intent:

Construction activities may comprise as much as 40% of all raw materials extracted from the earth. At the same time, construction, remodeling, and deconstruction are blamed for generating 136 million tons of waste annually. Some waste material can easily be refitted back into a structure. The action would decrease both material use and waste. In addition, unneeded transportation costs associated with hauling could be eliminated.

Additional Information / How to Implement:

Develop and implement a plan to use materials prudently, regardless of their origination.

Resources:

- Inform, Inc., *Community Waste Prevention Toolkit: Construction and Demolition Fact Sheet*, http://www.informinc.org/fact_CWPconstruction.php#basics
- Government of Hawaii, *Minimizing Construction and Demolition Waste,* http://www.hawaii.gov/health/environmental/waste/sw/pdf/constdem.pdf
- California Integrated Waste Management Board (CIWMB), http://www.ciwmb.ca.gov
- CIWMB, *Recycled-Content Product Directory*, http://www.ciwmb.ca.gov/RCP/Product.asp?VW=CSI&CATID=269
- NAHB Research Center, ToolBase Services, *Construction Waste Management,* http://www.toolbase.org/secondaryT.asp?TrackID=&CategoryID=34
- Whole Building Design Guide, *Construction Waste Management Database,* http://www.wbdg.org/ccbref/cwm.php
- Washington State Department of General Administration, Construction Waste Management Guide, http://www.ga.wa.gov/EAS/CWM/ContractorsGuide.doc

2.3.2 Reuse salvaged materials, where possible.

Intent:

To minimize the waste stream by re-using materials. Ideally, salvaged materials should be reclaimed from a nearby or onsite demolition or remodeling project so that transportation is minimized.

Additional Information / How to Implement:

Note: building materials can come from the deconstructed building in 2.3.1 or from another source.

Note – the word "component" is used in certain line items in this section (2.3.2; 2.4.1; 2.5.3; 2.6.1; 2.6.2; 2.7.1; and 2.8.1). A *component* is defined as part of an entire building system, such as:

- footing,
- foundation walls,
- slab,
- floor framing,
- interior partitions,
- wall framing,
- roof framing,
- wall sheathing,

- roof sheathing,
- wall insulation,
- attic insulation,
- windows,
- interior doors,
- exterior doors,
- interior trim,
- flooring trim,
- finish trim,
- siding,
- other.

Salvaged materials can be used for fill material, base for paved areas, or within building(s). Materials may include, but are not limited to, crushed concrete, salvaged wood, steel, brick, salvaged architectural materials such as windows, doors, paneling, and cabinets.

Salvaged windows and exterior doors should not be used at the expense of energy efficiency.

Disclaimer - Salvaged materials must meet minimum standards for materials, where applicable. In addition, a caveat to this line item is to be careful of lead paint and other potentially hazardous finishes that could be part of existing materials.

Points can be provided if the total cost of the salvaged materials (including material costs and labor costs, i.e., installed costs) is equal to or greater than 1% of construction costs.

Resources:

- Jennifer Corson, *The Resourceful Renovator: A Gallery of Ideas for Reusing Building Materials* (Chelsea Green Publishing Company, December 2000).
- Greater Vancouver Regional District Policy and Planning Department, *Old to New Design Guide Salvaged Building Materials in New Construction 3rd Edition* (January 2002), http://www.buildsmart.ca/pdfs/DesignGuideMaster.pdf.
- Used Building Materials Association, http://bcn.boulder.co.us/environment/ubma/index.html.

2.3.3. Dedicate and provide onsite bins and/or space to facilitate the sorting and reuse of scrap building materials.

Intent:

This practice will establish a central storage area to encourage maximizing usage of all materials on the site. Workers are less likely to waste material that will be subject to future inspection, those same workers are more likely to seek and use scraps if they know where to find them quickly, and the remnants that were not incorporated into the job are already sorted for grinding or recycling.

Additional Information / How to Implement:

Information will be added in Version 2.

Resources

Scopes of work should include the removal of remnants from in and around the building to a designated central area. The re-use area should be well conveniently located and marked or delineated for the size, type, and quantity of material that would be expected.

2.4 Use recycled content materials

2.4.1. Use recycled content building materials.

Intent:

To minimize the impact of home building on the environment.

Additional Information / How to Implement:

Points: In order to obtain the three points, the project must have a minimum of two types of recycled content materials. Each type of recycled content material used thereafter would give the project another point each, to a maximum of six points.

A builder can obtain three points for this line item by incorporating at least two different types of recycled content building materials into the home's construction. An additional point is awarded for each additional type of material for a maximum point total of five points.

Post-consumer means that the materials have been used by a consumer. Post-industrial can include waste materials from within a manufacturing site that is fed back into the manufacturing process as feedstock AND materials from outside the plant that is waste elsewhere, has not gone to a landfill or consumer yet, but is incorporated into a product's manufacturing process (e.g., fly ash for concrete).

The results of a California Integrated Waste Management Board (CIWMB) study on building material emissions indicate that recycled content products perform about the same as standard products. Both alternative and standard products have the potential to emit chemicals of concern. For a copy of the study, see http://www.ciwmb.ca.gov/Publications/GreenBuilding/43303015.doc

Here are some typical ranges of recycled content found in various construction materials:

Clay brick is manufactured with a variety of recycled materials. Examples include contaminated soils, scrap soils from excavations, inclusion of bottom ash from coal-fired generators, and production scrap from other ceramic products. The amount of recycled materials in clay brick depends on the type of material added, but typical values range up to 7% by weight.

Through the Composite Panel Association's Environmentally Preferable Product (EPP) Specification CPA 1-02, composite panels (particleboard, medium density fiberboard (MDF), and hardboard) can be certified to have 100% recycled or recovered fiber. See the Resources section of this line item for further information.

Cellulose insulation can contain as much as 85% recycled paper stock (wood-based) content. Additionally, it is certified in accordance with ASTM 739 and the Cellulose Insulation Manufacturers Association.

Fiberglass insulation = 25% combination post- and pre-consumer recyclables

Steel framing = 25% of which no less than 10% should be post-consumer recycled.

Carpeting: Recycled content carpet is available for residential construction.

Flyash or slag: Flyash or slag, byproducts of the steel production process, can be used in concrete as a replacement for some of the cement. In some cases, as much as 40% of the cement can be substituted while maintaining required strength and durability. Many concrete suppliers are familiar with recycled content options and some have reported that the use of flyash or slag is standard practice. Several contractors have reported that the flyash-content concrete sets up more slowly and adjustments must be made in the timing of finishing. Also, flyash- or slag-content concrete may have some dark streaking and therefore, may not be suitable for exposed flatwork or poured walls. Check with you local concrete supplier.

Road and paver base, gravel: In many parts of the country, efforts are underway to recycle concrete waste. Concrete is ground into useable materials for temporary construction roads, a base for pavers or bricks, or other possible uses in place of limestone or gravel. In some cases, concrete suppliers have developed and tested mixes in which some recycled concrete is used. Check with local concrete suppliers or landfills to see if recycled concrete aggregate is available.

Information about local recycling programs should be inserted here. The use of recyclable materials is also recommended. Products that are either recycled or recyclable will display the triangle logo (see above). The product literature must note the recycled content, if any. The reference section contains additional information on this.

<u>Resources:</u>

- King County (WA), *Environmentally Responsible Carpet Choices,* http://www.metrokc.gov/procure/green/carpet.htm
- U.S. Environmental Protection Agency (EPA), *Comprehensive Procurement Guidelines*, http://www.epa.gov/cpg/.
- EPA, *Environmentally Preferable Purchasing.* http://www.epa.gov/oppt/epp/tools/toolsuite.htm
- Green Building Source, *Green Product Information* http://oikos.com/products/index.lasso
- California Integrated Waste Management Board, <u>Recycled Product Directory,</u> *Products Category: Construction,* can provide a baseline for total recycled

content (TRC) that is achievable with some products, http://www.ciwmb.ca.gov/RCP/Product.asp?VW=CAT&CATID=257

- Details on the Composite Panel Association's Environmentally Preferable Product (EPP) Specification CPA 1-02 and a list of certified manufacturers, http://www.pbmdf.com/AboutCPA/EPP.asp
- Carpet America Recovery Effort[SM], http://www.carpetrecovery.org/
- Steel Recycling Institute, http://www.recycle-steel.org/construction.html

Excerpt from the Federal Trade Commission's "Part 260 -- *GUIDES FOR THE USE OF ENVIRONMENTAL MARKETING CLAIMS... (d) Recyclable:*" It is deceptive to misrepresent, directly or by implication, that a product or package is recyclable. A product or package should not be marketed as recyclable unless it can be collected, separated or otherwise recovered from the solid waste stream for reuse, or in the manufacture or assembly of another package or product, through an established recycling program. Unqualified claims of recyclability for a product or package may be made if the entire product or package, excluding minor incidental components, is recyclable. For products or packages that are made of both recyclable and non-recyclable components, the recyclable claim should be adequately qualified to avoid consumer deception about which portions or components of the product or package are recyclable. Claims of recyclability should be qualified to the extent necessary to avoid consumer deception about any limited availability of recycling programs and collection sites. If an incidental component significantly limits the ability to recycle a product or package, a claim of recyclability would be deceptive. A product or package that is made from recyclable material, but, because of its shape, size or some other attribute, is not accepted in recycling programs for such material, should not be marketed as recyclable...

Source, Federal Trade Commission, *Part 260–Guides for the Use of Environmental Marketing Claims*, http://www.ftc.gov/bcp/grnrule/guides980427.htm

2.5 Recycle waste materials during construction.

Recycling waste materials is driven by market conditions at the local level throughout which recycling markets and tipping fees vary greatly.

2.5.1. Develop and implement Construction and Demolition (C & D) waste management plan that is posted at jobsite.

Intent:

Create a C & D waste management plan that sets goals to recycle or salvage a minimum of 50% (by weight) of construction, demolition, and land clearing waste.

Additional Information / How to Implement:

A C & D plan can be a simple spreadsheet that covers the materials used or de-constructed on site and the plan for reusing them onsite, or recycling them. If recycling, include the name of the hauler, destination, and approximate quantities. A sample plan can be obtained from the City of Oxnard, CA in the Resources.

Resources:

- City of Oxnard (CA), *C & D Solid Waste Management and Recycling Plan,* http://www.ci.oxnard.ca.us/pubworks/refuse/worksheets/c_dplan.pdf
- NAHB Research Center, Inc., Residential Construction Waste information, http://www.epa.gov/epaoswer/non-hw/debris/mgmt.htm
- U.S. Environmental Protection Agency Solid Waste and Emergency Response, Building Savings, Strategies for Waste Reduction of Construction and Demolition Debris from Buildings (EPA-530-F-00-001) (June 2000), http://www.epa.gov/osw
- Institute for Local Self-Reliance. http://www.ilsr.org/recycling/buildingdebris.pdf.

2.5.2. Conduct onsite recycling efforts, e.g., use grinder and apply materials onsite, thus reducing transportation-related costs.

Intent:

Through grinding, divert from the landfill a minimum of 50% (by weight) of construction, demolition, and land clearing waste. Reduce transportation-related environmental costs.

Additional Information / How to Implement:

This task may also be part of the builder C & D plan. Grinding and other methods of onsite processing and reuse of waste require an economic analysis. Large homebuilders have reported successful integration of a grinder into field operations. (See Waste Handling Equipment news article in References.) For small volume builders it not likely be cost effective to own or rent grinding equipment. There may, however, be a local business that could service a small job efficiently.

Resources:

- Waste Handling Equipment News, *Major Home Builders Benefit from On-site Recycling,* http://www.wastehandling.com/july/major.html
- NAHB Research Center, ToolBase Services, *RESIDENTIAL CONSTRUCTION WASTE: FROM DISPOSAL TO MANAGEMENT,* http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=34&DocumentID=2301

2.5.3. Recycle construction waste offsite, e.g., wood, cardboard, metals, drywall, plastics, asphalt roofing shingles, concrete, block, other.

Intent:

Through a recycling program, divert from the landfill a minimum of 50% (by weight) of construction, demolition, and land clearing waste.

Additional Information / How to Implement:

Points: At least two types of materials must be recycled to obtain the six points. Each type of material recycled thereafter yields two points each, to a maximum of twelve points.

This task may also be part of the builder C & D plan. It involves the successful offsite recycling of materials that might otherwise have been sent to the landfill.

Resources:

- The U.S. General Services Administration (GSA) has recently updated its online Construction Waste Management Database to assist the building industry in reducing construction and demolition waste. Recyclers of construction and demolition waste may advertise their services free on this site. Access the database at http://cwm.wbdg.org.
- American Forest and Paper Association, National Wood Recycling Directory, http://www.afandpa.org/Content/NavigationMenu/Environment_and_Recycling/Recycling/Wood_Recovery1/Wood_Recycling_Directory1/Wood_Recycling_Directory_Intro.htm.
- California Integrated Waste Management Board, http://www.ciwmb.ca.gov/.
- Corrugated Packaging Council, How to Recycle Corrugated, http://cpc.corrugated.org/Recycle/RecyHowTo.aspx.
- U.S. Environmental Protection Agency Municipal and Industrial Solid Waste Division Office of Solid Waste, *Characterization of Building-Related Construction and Demolition Debris in the United States* (EPA530-R-98-010) (June 1998), http://www.epa.gov/epaoswer/hazwaste/sqg/c&d-rpt.pdf.
- Steel Recycling Database, http://www.recycle-steel.org/database/main.html

2.6 Use renewable materials

2.6.1. Use materials manufactured from renewable resources (e.g., agricultural byproduct-based such as soy-based insulation; bamboo; wood-based products)

Intent:

Use building products that use carbon sequestration, i.e., that are made from plants that take carbon from the atmosphere and store it as fiber.

Additional Information / How to Implement:

Points: A builder can obtain three points for this line item if they incorporate at least two different types of renewable resources into the home's construction. An additional point can be obtained for each additional type of material for a maximum point total for this line item not to exceed five points.

Careful review of the material manufacturer's claims and material specifications is required for this task. Points should be given for each material specified and used.

Note: products that comply with this section of the User Guide should also comply with the Indoor Environmental Quality section of the User Guide. For example, composite wood or agrifiber panel products should not contain process added urea-formaldehyde resins or must be third party certified for low formaldehyde emissions. Particleboard, medium density fiberboard (MDF) and hardwood plywood substrates must be certified to low formaldehyde emission standards ANSI A208.1, ANSI A208.2 and ANSI/HPVA HP1, respectively (see Section 5.1.5). Similarly, bamboo flooring manufacturers should produce a copy of the lab test results, by an American laboratory, for their products. The results should include a formaldehyde test and a hardness and stability (expansion/contraction) test.

Resources:

Information will be added in Version 2.

2.6.2 Use certified wood for wood and wood-based materials and products from all credible third party certified sources.

Intent:

Preserving our natural resources includes the commitment to best practices in forest management, like practices that maintain and restore the health of the forests and its ecosystems. Forest certification systems help identify producers that assure a reliable supply without damaging the forests.

Additional Information / How to Implement:

A comparison list of the North American certifiers is provided by the Forest Certification Resource Center, in References.

Below is a list of the third-party certified wood sources.

- The Sustainable Forestry Initiative® Program
- The American Tree Farm System®
- The Canadian Standards Association's Sustainable Forest Management System Standards (CAN/CSA Z809)
- Forest Stewardship Council (FSC)
- Program for the Endorsement of Forest Certification Systems (PEFC), and
- Other such credible programs as they are developed and implemented.

Resources:

- Forest Certification Resource Center, *Comparison of Forest Certification Systems*,
- http://www.certifiedwood.org/search-modules/compare-systems/comparison-of-systems/comparison-of_systems.htm
- The Sustainable Forestry Initiative® Program, http://www.aboutsfi.org/
- The American Tree Farm System® http://www.treefarmsystem.org/
- The Canadian Standards Association's Sustainable Forest Management System Standards (CAN/CSA Z809) http://www.sfms.com/welcome.htm
- Forest Stewardship Council (FSC) http://www.fsc.org/fsc
- Program for the Endorsement of Forest Certification Systems (PEFC) http://www.pefc.org/internet/html

2.7 Use resource efficient materials

2.7.1. Use products that contain fewer resources to meet the same end-use as traditional products.

Intent:

Minimize the resources consumed by and environmental impact of building a house.

Additional Information / How to Implement:

Points: A project must use resource efficient materials for at least two different types of components to receive the three points.

When specifying materials, consider the amount of resources going into the product and whether other alternatives are available. Examples are specifying hollow brick that meets the requirements of ASTM C 652 and is made from less material than face brick that meets ASTM C 216. Appearance and durability requirements are identical. Or, specifying engineered wood products, e.g., I-joists that use 35% less fiber material than solid-sawn products.

Caveat: even though engineered products can reduce the amount of feedstock used in a product, e.g., wood fiber in I-joists, more energy or binders may be needed to create the final product. While this may be the case, our intent is to reduce the core source of material going into the product's creation.

Resources:

- DOE's Energy Efficiency and Renewable Energy, *Energy and Environmental Guidelines for Construction,* http://www.eere.energy.gov/buildings/info/design/construction.html#construction

2.8 Innovative options

2.8.1 Use locally available, indigenous materials.

Intent:

To make the home building process more environmentally acceptable by minimizing transportation and processing costs and using materials that are common in the local region.

Additional Information / How to Implement:

A builder can obtain three points for this line item if they incorporate at least one type of locally available, indigenous material into the home's construction. An additional point can be obtained for each additional type of material for a maximum point total of five points.

Guidance to program administrators: Points should be awarded in this section based on criteria such as 10% of the building materials are extracted, processed, and manufactured within a 300-mile radius or within a 1000-mile radius if shipped by rail, or a combination of the two distances.

Resources:

Information will be added in Version 2.

2.8.2. Use a life cycle assessment (LCA) to compare the environmental burden/effects of building materials. Based on the analysis, choose the most environmentally preferable product for that building component.

Intent:

To highlight the best use of resources, including cost, to assure that all of the guiding principles have been considered.

Additional Information / How to Implement:

A life cycle assessment (LCA) is considered to be a reliable way to calculate and compare the cradle-to-grave environmental effects and costs of common building materials. Designers can use modeling tools such as Athena™ to examine the lifecycle environmental effects of a complete structure or of individual assemblies, and can experiment with alternative designs and material mixes to arrive at the best environmental footprint. A software tool such as BEES (http://www.bfrl.nist.gov/oae/software/bees.html) can also identify the life cycle costs of select building components.

The objective of the modeling is to aid the designer in selecting building assemblies and/or materials with the lowest reported impact in terms of energy consumption, air and water toxicity index, GWP, ecologically weighted resource use, and solid waste emissions.

Suggested course of action:

1. Develop building design using materials with a low environmental impact. Evaluate building materials for each life cycle phase using either the manufacturer's data or a reputable LCA.
2. Establish a process to compare and assess similar building materials, in similar categories.
3. Survey manufacturers to analyze the environmental impacts at each phase of a product's life, making it possible to explore the environmental effects of design options or material mixes in order to arrive at the best green design.
4. Use the Athena™ tool to assess building assemblies.

Another suggested two-step process:

1. Conduct preliminary research and an evaluation of building materials generically, such as concrete, steel, and wood. Explore the environmental effects of different design options or material mixes.
2. Provide evidence that the selection of the foundations and floor assembly materials, structural system (column and beam, or post and beam combinations), roof and envelope assembly materials (cladding, windows etc.) included a life cycle assessment.

Resources:

- National Institute of Standards and Technology, *Building for Environmental and Economic Sustainability software,* (http://www.bfrl.nist.gov/oae/software/bees.html)
- The Athena™ Sustainable Materials Institute, http://www.athenasmi.ca/news/down/LCI_Database_Project_News_1.pdf

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SECTION 3
ENERGY EFFICIENCY

3.1 Implement an integrated and comprehensive approach to energy-efficient design of building site, building envelope, and mechanical space conditioning systems

Intent:

To use a whole systems approach in designing and building an energy efficient home. Key concepts are *integrated* and *comprehensive*.

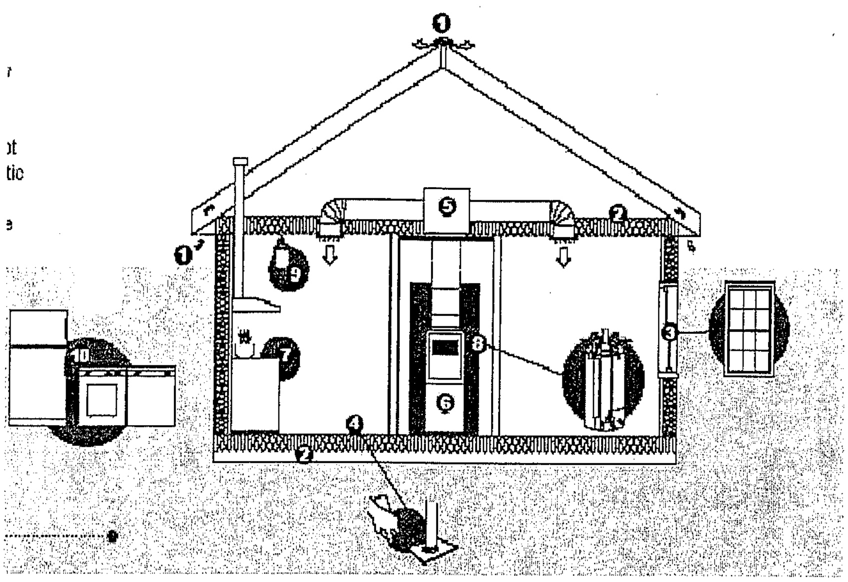
Information / How to Implement:

Pay attention to multiple facets related to energy efficiency during the design and construction process. For instance, rather than simply focusing on individual decisions related to energy efficiency, such as the R-value of attic insulation, consider the implications of each choice on the performance of the whole house. Balance the cost and performance of each component of the home system, such as a well-insulated building envelope (foundation, walls, and attic); windows recommended for the climate by experts such as the Efficient Windows Collaborative, the Department of Energy, and/or local energy professionals; a thorough and carefully-implemented air sealing package; climate-appropriate heating and cooling equipment that balances efficiency with cost effectiveness; sealed ductwork kept within the conditioned space; and efficient water heating equipment and distribution. Moisture and indoor environmental quality are closely related factors that are affected by energy efficiency measures.

For more detailed information and explanation about the sizing and design of space heating and cooling, refer to "Understanding HVAC System Design Issues" at the end of this Energy Efficiency section.

Resources:

- *Home Energy Checklist* (EEBA) http://www.eeba.org/technology/publications/hec/default.htm
- *Whole House Energy Checklist* (U.S. DOE fact sheet), http://www.southface.org/web/resources&services/publications/technical_bulletins/WH-Energy%20Checklist%20GO-10099-766.pdf
- *Energy Efficiency Pays* (U.S. DOE fact sheet), http://www.southface.org/web/resources&services/publications/technical_bulletins/EEP-Efficiency_pays%2099-746.pdf
- *Considerations for Building a More Energy Efficient Home*, NAHB Research Center fact sheet. Available at http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1809&DocumentID=4168



Improve Energy Efficiency Throughout the House

1. Provide roof/attic ventilation
2. Install adequate insulation with no gaps or compressed areas.
3. Specify efficient windows; consider window orientation.
4. Seal all penetrations.
5. Locate all ducts within conditioned space; ensure all ducts are sealed with mastic.
6. Size heating and cooling equipment; choose efficient models.
7. Provide controlled ventilation.
8. Install efficient water heating.
9. Specify efficient lighting for fixtures used more than 4 hours per day.
10. Choose efficient appliances.

Courtesy of Southface Institute; developed with funding from the U.S. Department of Energy

Requirements:

3.1.1 Home is equivalent to the IECC 2003 or local energy code whichever is more stringent. Conformance to this threshold shall be based on plan analysis using software such as REScheck or other as approved by green building program administrator or NAHB.

3.1.2 Space heating and cooling system/equipment shall be sized according to building heating and cooling loads calculated using ANSI/ACCA Manual J 8th Edition or equivalent. Computerized software recognized by ACCA as being in compliance with Manual J 8th Edition may be used.

3.1.3. Conduct third party plan review to verify design and compliance with Section 3. When multiple homes of the same model are to be built by the same builder, a representative sample of homes (15%) may be reviewed subject to a sampling protocol.

Intent:

To establish a minimum energy threshold for all NAHB certified green homes

Information / How to Implement:

If you are building under the jurisdiction of the 2003 International Energy Conservation Code (IECC), your home will meet this requirement. If you do not follow the IECC 2003, you can determine if your project meets this energy code by using REScheck, a free, easy-to-use software package.

Resources:

- ***REScheck*** is a free software tool that can be downloaded at http://www.energycodes.gov/rescheck/.

- ❖ ***Manual J 8th Edition*** is available through the Air Conditioning Contractors of America and can be purchased online at http://www.accaconference.com/Merchant2/merchant.mv?Screen=SFNT&Store_Code=ACCOA . Also, see www.acca.org for additional approved third-party software providers.
- ❖ *Heat Loss Calculation Guide H-22*, Hydronics Institute Division of GAMA, 2001.
- ❖ *International Energy Conservation Code (IECC) 2003.* Available from the International Code Council, http://www.iccsafe.org
- ❖ REScheck, available for free download at http://www.energycodes.gov/rescheck/
- ❖ Third party plan review: A Certified Home Energy Rating System (HERS) rater. A directory of Home Energy Raters can be found on the ENERGY STAR® website at www.energystar.gov.

3.2 Performance measures

Optional guidelines – At least 37 points must be obtained from the line items under the Energy Efficiency section to qualify your project as a green home at the Bronze level. The Silver level requires 62 points and the Gold level 100 points.

3.2.1 Home is X % above IECC 2003:

A. 15%

B. 30%

C. 40%

Intent: 

To offer builders a flexible, performance-based means of achieving higher levels of energy performance than the IECC 2003. An ENERGY STAR home is approximately 15% more energy efficient than a home that meets the IECC 2003. Some builders are now achieving a 40% or 50% improvement.

Information / How to Implement:

Use REScheck to examine the effect of different levels of insulation, window U-values and SHGC factors, and space conditioning equipment efficiencies to identify a cost-effective system for your project. The appropriate level of energy performance above IECC 2003 will vary depending upon the severity of the climate, but building to the equivalent of ENERGY STAR is usually cost effective for consumers in most regions of the country.

Resources:

- ❖ *REScheck* - REScheck, available for free download at: http://www.energycodes.gov/rescheck/

- *International Energy Conservation Code* (IECC) 2003. Available from the International Code Council, http://www.iccsafe.org

3.3 Prescriptive path

Alternate method for gaining points for energy efficiency.

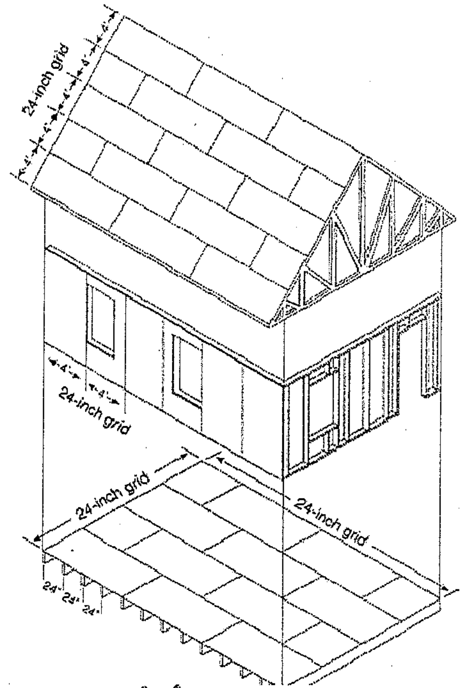
3.3.1 Building envelope

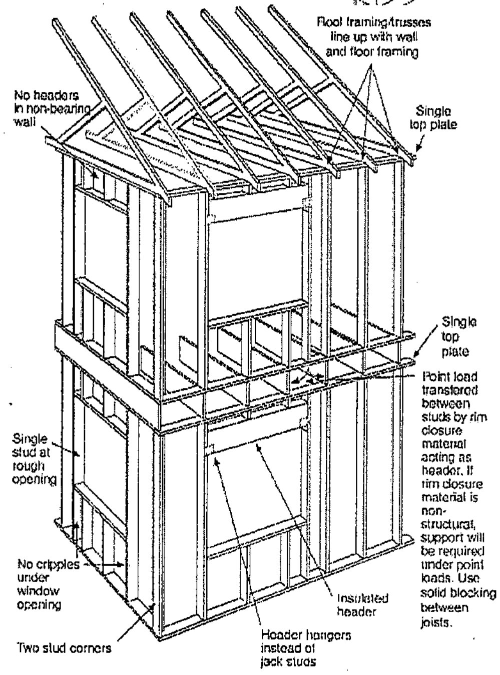
A. Increased effective R-value of building envelope using advanced framing techniques, continuous insulation, and/or integrated structural insulating system. Measures may include but are not limited to:

- SIPS*
- ICFs*
- Advanced Framing

- Insulated corners and interior/exterior wall intersections*
- Insulated headers on exterior walls
- Raised heel trusses
- Continuous insulation on exterior walls, cathedral ceiling, attics

- This line item also has a resource-efficiency benefit





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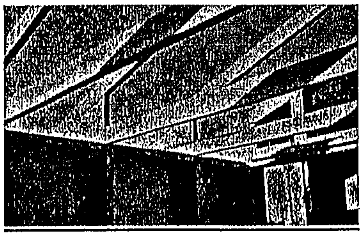

Raised Heel Truss

Intent:

To enhance the insulating value of the building envelope by selecting an efficient and cost-effective framing package or alternative structural wall system. Framing details such as two-stud corner framing, ladder blocking at wall intersections, and raised heel roof trusses can eliminate thermal bridges, i.e., areas where there is no room for insulation

Information / How to Implement:

The Resources listed below will help identify methods for insulating walls to the fullest extent and avoiding thermal bridging.

Resources:

- *Reduce Framing Costs with Advanced Framing Techniques*, U.S. EPA: http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/BuilderGuide3D.pdf
- *Advanced Framing Fact Sheet*, U.S. DOE: http://www.toolbase.org/docs/MainNav/WoodFrameConstruction/3949_advancedwallframing1.pdf
- Advanced framing: http://www.buildingscience.com/housesthatwork/advancedframing/default.htm
- *Cost Effective Homebuilding: A Design and Construction Handbook*, 1994, NAHB Research Center, available for purchase at: http://www.nahbrc.org/tertiaryR.asp?TrackID=&DocumentID=2584&CategoryID=917

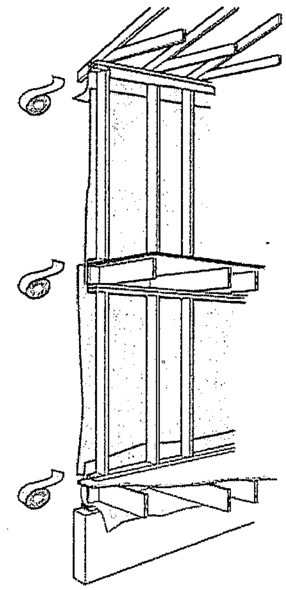
B. Incorporate air sealing package to reduce infiltration. (All measures that apply to project must be performed.)

- Sill sealer between foundation and sill plate.
- Caulk bottom plate of exterior walls.
- Air seal band joist cavities between floors.

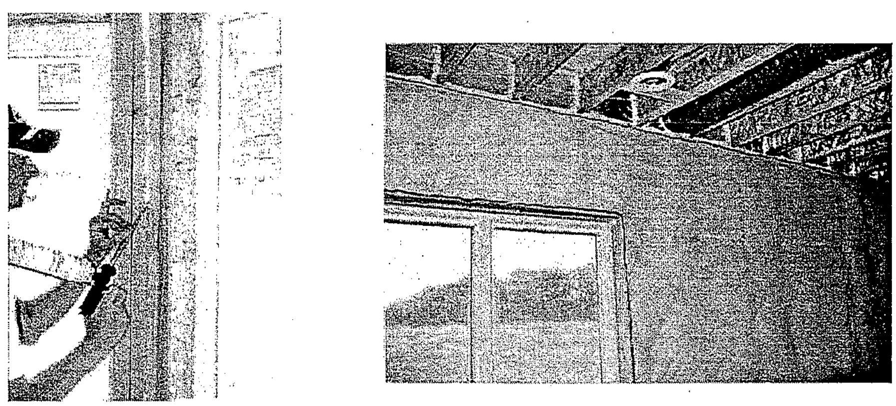
  Ensure air barrier continuity at all framed cavities such as air chases, soffits, coffered or dropped ceilings, and behind tub/shower units on exterior walls.

From www.oikos.com

- Caulk/foam all electrical, plumbing, heating penetrations between floors (including attic, basement, crawl space, and garage) and to exterior
- Block and seal cantilevered floors and kneewalls.
- Weatherstrip attic hatches, kneewall doors.
- Insulate, caulk, or foam between window/door jambs and framing.
- If installing recessed lights in ceilings adjacent to unconditioned space, use rated, air-tight Type IC housings.
- Caulk/foam HVAC register boots to subfloor or drywall that penetrate the building envelope.
- If a fireplace is installed, install a gas fireplace that is sealed combustion or a wood-burning fireplace with gasketed doors.



Housewrap Installation



Air Sealing Details

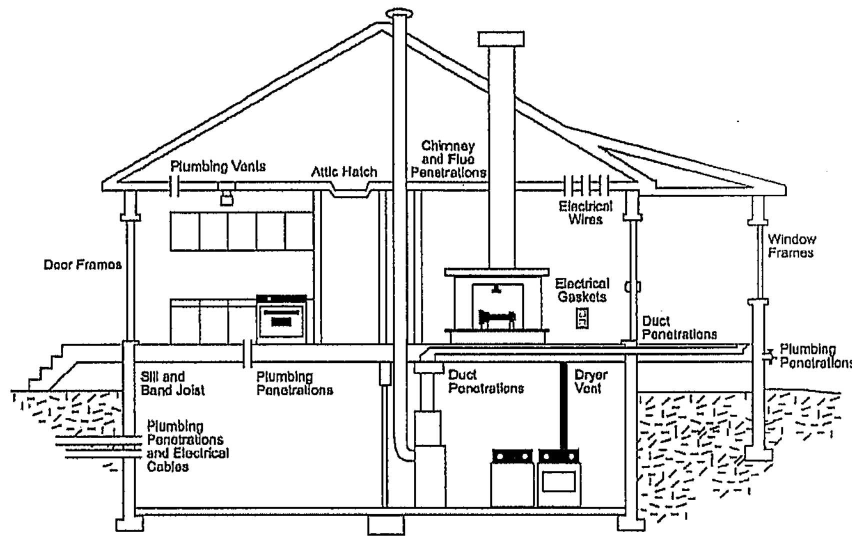
Intent:

When building an energy efficient home, it is equally or more important to prevent air infiltration as it is to provide a high R-value wall system. Air can pass through very small cracks, resulting in energy loss and condensation, so it is necessary to be very detail-oriented when it comes to air sealing.

Information / How to Implement:

See also Section 5.2.2 under the Indoor Environmental Quality section for more information about mechanical ventilation options.

Air leakage can account for as much as 20-30% of energy loss through the building envelope. Although insulation reduces energy loss , air infiltration can compromise the efficiency of a building because it brings conditioned air directly outdoors (or outdoor air inside), bypassing the insulation. In addition, it not only carries heated (or cooled) air to the outdoors, but may also create moisture problems as water vapor in the air moves from a warmer to colder location and condenses. Use the list above to make sure that you seal the nooks and crannies where air may escape.



Typical Locations of Air Leakage

To perform air sealing, use a variety of materials such as caulk, foam, and gasket materials. It has been proven that "chinking" with fiberglass insulation does not prevent airflow. Low-expanding foams should be used around windows and doors so that the frame doesn't bind—a common complaint with first-generation, high-expanding foam products.

In conjunction with implementing an air sealing package, also consider a means of providing fresh air to the home. This may be operable windows if the homeowner will use them, but often an automatic mechanical means of introducing fresh air may be the most reliable way to ensure adequate ventilation. Controlled ventilation that is carefully designed and installed provides a more consistent rate of air exchange compared to simply building a leaky structure. A tight building envelope with an intentional means of introducing outdoor air enhances energy efficiency, comfort, and indoor air quality. See the Indoor Environmental Quality section for additional information about mechanical ventilation.

Resources:

- *Advanced Air Sealing* (book available for viewing online): http://oikos.com/library/airsealing/index.html
- U.S. DOE's fact sheet, *Airtight Drywall Approach* (no diagrams), http://www.eere.energy.gov/consumerinfo/fact sheets/bd8.html

- Southface Energy Institute's fact sheet, *Airtight Drywall Approach* (contains diagrams), http://www.southface.org/web/resources&services/publications/factsheets/24ada_drywal.pdf

C. Use ENERGY STAR – rated windows appropriate for local climate.

Intent:

To assure optimum building envelope performance. Window area often comprises a substantial portion of the wall area in new homes. Compared to an opaque insulated wall, windows offer only about 15% to 25% of the R-value. In addition, they are a source of direct solar gains in the summer which can add to the cooling load.

Information / How to Implement:

Select windows featuring the Energy Star label. Alternately, visit the Website of the Efficient Windows Collaborative to see which type of glazing is recommended for your climate. Low-E coatings for windows are recommended for almost all regions of the U.S. Generally look for windows with as low a U-value as is affordable—they offer the best insulating value (U-value is the inverse of R-value). In cooling-dominated climates, use a window that has a low SHGC. Always choose a frame type that provides a thermal break, e.g., wood, composite, vinyl, or aluminum with a thermal break. Using high efficiency windows can not only enhance thermal performance, but also reduces the risk of condensation on windows. For passive solar designs and homes that are constructed with large amounts of glazing in a specific orientation, it is helpful to use windows selected for each orientation (e.g., high SHGC on south face for direct solar gain). Refer to the Resources for a more detailed understanding of how window technologies perform in various climates.

Resources:

- www.efficientwindows.org
- *Improve Energy Efficiency with High Performance Windows*, ENERGY STAR fact sheet, http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/BuilderGuide3E.pdf
- Efficient Windows Collaborative, http://www.efficientwindows.org. Recommends U-value and Solar Heat Gain Coefficient (SHGC) by climate region.
- ENERGY STAR Website www.energystar.gov for list of stores that sell ENERGY STAR labeled windows
- www.energystar.gov for a list of manufacturers searchable by type of window, type of frame, and climate.
- The National Fenestration Rating Council (NFRC) labels windows for U-value and Solar Heat Gain Coefficient and has searchable directory of windows meeting specific criteria on their Website at http://www.nfrc.org

3.3.2. HVAC design, equipment, and installation

A. Size, design, and install duct system using ANSI/ACCA Manual D® or equivalent.

Intent:

Getting the proper amount of airflow to and from each room is as important to comfort and efficiency as the equipment itself. Careful sizing and layout according to recognized industry standards is essential to ensuring adequate air delivery and therefore, comfort.

Information / How to Implement:

Ask your HVAC contractor to use ACCA Manual D to size and lay out supply and return ductwork to each area of the home. Manual D will recommend duct diameter to fit the load in each room taking into account the length of the duct run and the type of duct being used. Request a copy of the Manual D printout. After the system has been installed, take a look around to make sure that the installation is in accord with the design and that there are no sharp bends or poor connections.

Resources:

- *ACCA Manual D®, Residential Duct Systems* (available for purchase at http://www.acca.org)
- *Air Distribution System Design* (U.S. DOE fact sheet) http://www.toolbase.org/docs/MainNav/Energy/4074_doe_airdistributionsystemdesign.pdf
- *A Builder's Guide to Placement of Ducts and HVAC Equipment in Conditioned Spaces*, 2000, NAHB Research Center. Available for $5 from NAHB Research Center bookstore at http://nahbrc.org/tertiaryR.asp?TrackID=&DocumentID=2570&CategoryID=110
- *Design and Construction of Interior Duct System*, Florida Solar Energy Center, (2002) http://www.fsec.ucf.edu/bldg/baihp/pubs/Papers/interior_ducts.pdf

B. Design radiant or hydronic space heating systems using industry-approved guidelines, e.g., *Guidelines for the Design and Installation of Radiant Panel Heating and Snow/Ice Melting Systems* by the Radiant Panel Association, *Heat Loss Guide (H-22),* by the Hydronics Institute Division of GAMA or accredited design professionals and manufacturer's recommendations.

Intent:

To ensure proper design of hydronic and radiant space heating systems by using industry expertise. Hydronic and radiant systems require the same attention to detail as forced air systems. Components such as piping and pumps must be properly sized and matched according to the equipment being used.

Information / How to Implement:

Ask your HVAC contractor to use the Radiant Panel Association design guidelines when designing a hydronic system. There are training and certification programs through the Radiant Panel Association for HVAC contractors

Resources:

- *Quick Reference to RPA Guidelines for Hydronic Radiant Floor Heating, Radiant Panel Association (RPA)*, http://www.radiantpanelassociation.org/files/public/GdlnQuick.htm. (Entire guidelines available to download for $15 at http://www.radiantpanelassociation.org/i4a/store/category.cfm?category_id=8)
- *List of RPA certified contractors,* available at http://www.radiantpanelassociation.org

C. Use ANSI/ACCA Manual S® or equivalent to select heating and/or cooling equipment.

Intent:

Manual S is the second step in assuring proper design of a space heating and/or cooling system. After using Manual J to calculate the building's heating and cooling load, use Manual S to assist in selecting and sizing equipment that will satisfy the latent and sensible heating and cooling loads.

Information / How to Implement:

Ask your HVAC contractor to use ACCA Manual S in selecting the heating or cooling equipment for the home. By reviewing this process, you can better understand some of the issues involved and help guide customers' decisions about their heating and cooling system. Very efficient homes that require less energy for heating and cooling are much more sensitive to proper HVAC equipment sizing.

Resources:

- ACCA Manual S®, *Equipment Selection*, available for purchase at www.acca.org.
- U.S. DOE fact sheet, *Right Size Heating and Cooling Equipment*, http://www.toolbase.org/docs/MainNav/Energy/4073_doe_hvacsizing.pdf

D. Verify performance of the heating/cooling system. HVAC contractor to perform the following:

- Start-up procedure according to manufacturer's instructions
- Refrigerant charge verified by super-heat and/or sub-cooling method
- Burner set to fire at nameplate input
- Air handler setting/fan speed
- Total air flow within 10% of design flow
- Total external system static should not exceed equipment capability at rated airflow.

Intent:

Verification of performance provides a final assurance that the system has been designed, installed, and commissioned as intended. Items can easily be overlooked during a busy construction schedule – even given the most conscientious approach.

Information / How to Implement:

Ask your HVAC contractor to carefully follow the startup procedure outlined in the equipment literature. Ask for a checklist of the recommended startup procedure.

Resources:

- North American Technician Excellence. Operates a certification program for HVAC technicians. Maintains a database of certified technicians at http://www.natex.org/ or by calling 877-420-NATE.
- Manufacturer's Website or printed installation instructions.

E. Use HVAC installer and/or service technician who are certified under a nationally or regionally recognized program such as NATE, BPI, RPA, or manufacturers' training.

Intent:

The programs citied above are the equivalent of a "technical degree" for a HVAC contractor. With an HVAC trade contractor who has completed a certification, you and your customer can have added assurance that the HVAC system in the home is designed and installed in accordance with the industry's best recommended practices

Information / How to Implement:

Encourage your contractor to investigate the local availability of HVAC training and certification programs. Ask for certifications when seeking proposals. Some agencies maintain a database of certified contractors; consider using HVAC contractors in your area that have been certified.

At the time of the printing of this document, the Air Conditioning Contractors of America (ACCA) is in the process of establishing a contractor accreditation program that will ensure contractors perform quality installations.

Resources:

- NATEX Business Locator, available at http://www.natex.org/ or by calling 877-420-NATE. A searchable database of contractors certified by the National Association for Technician Excellence (NATE).
- The Building Performance Institute. Certifies whole-house performance contractors and provides a searchable database of certified contractors at, www.bpi.org.
- List of Radiant Panel Association members that are certified by RPA (for hydronic heating) http://www.radiantpanelassociation.org/.
- Manufacturers' Website for directory of contractors trained for proprietary equipment.
- www.acca.org.

F. Fuel-fired space heating equipment efficiency (AFUE):

	% Improvement above Federal minimum

Gas Furnace:	≥81%	3%
	≥88% (ENERGY STAR	10%
	≥94%	16%
Oil Furnace:	≥83%	5%
Gas or Oil Boiler:	≥85%	5%
	> 90%	10%

Note: Add 3 points associated with increasing AFUE if Manual S and D and start-up procedure are followed when one of the space heating units noted above is installed.

Intent:

As with cooling equipment, higher efficiency equipment will satisfy space heating requirements using less fuel.

Information / How to Implement:

Select equipment bearing the ENERGY STAR label or check manufacturer's literature for efficiency information. The American Council for an Energy-Efficient Economy (ACEEE) lists the highest efficiency equipment available (see Resources). The measure of furnace efficiency, Annual Fuel Utilization Efficiency (AFUE), is the ratio of heat produced per unit of fuel consumed, over the course of a heating season. Depending upon the fuel used in the home, ask your HVAC contractor about pricing higher efficiency furnaces or boilers. Typically, 81-83% AFUE furnaces carry little cost increase over those meeting federal minimum efficiency standards (currently 78%). Higher efficiency gas furnaces or boilers (greater than 90% AFUE) are usually direct vent, sealed combustion units and, because the flue gases are cooler, PVC pipe can often be used for venting, eliminating the need for a chimney. Through-the-wall venting may offset the higher cost of the equipment.

Keep in mind that sealed combustion equipment not only offers an energy efficiency benefit, but may be advantageous with respect to indoor environmental quality as well. The sealed combustion chamber eliminates any possibility of backdrafting or spillage of combustion gases into the home.

In many cases, it is advantageous to invest in high AFUE heating equipment in climates that have a significant heating load or high fuel costs. Energy efficiency investment dollars may be better spent elsewhere in cooling-dominated climates.

Resources:

- American Council for an Energy-Efficient Economy's list of most energy efficient appliances http://www.aceee.org/consumerguide/mostenef.htm
- http://www.energystar.gov for a list of equipment meeting ENERGY STAR standards
- *Gas Appliance Manufacturer's Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment.* http://www.gamanet.org

- Manufacturers' Websites.

G. Heat pump efficiency (cooling mode)

1. SEER 11-12* - (9%-17% improvement above SEER 10 air conditioner)
2. SEER 13-14 – (23%-29% improvement above SEER 10 air conditioner)
3. SEER 15-18 – (33% -44% improvement above SEER 10 air conditioner)
4. SEER 19+ - (47%+ improvement above SEER 10 air conditioner)
5. Staged air conditioning equipment

Split-systems must be ARI-tested as a matched set.

*SEER 13 will be federal minimum as of January 2006.

NOTE: Additional 3 points given if Manuals S and D have been used and start-up procedures are followed when one of the A/C units noted above is installed.

Intent:

High efficiency equipment uses less energy to accomplish the same task. The intent of this guideline is to reduce the electrical energy necessary to cool the home.

Information / How to Implement:

Select equipment that carries the ENERGY STAR label, or check manufacturer's literature for information on SEER. The ACEEE lists the highest efficiency equipment available (see Resources). Several issues to consider:

As of January 2006, the federal minimum efficiency for air conditioning units will be SEER 13. Oftentimes, it is more beneficial to concentrate on improving design, installation, and commissioning procedures before simply installing equipment with a higher SEER rating. For instance, proper sizing, insulating, and sealing of ductwork can reduce the amount of energy loss and increase occupant comfort as well. Even the most efficient equipment cannot make up for deficiencies in a distribution system or inadequate sizing and commissioning. Before investing in more efficient cooling equipment, invest proper sizing, design, installation, and commissioning of the entire system.

To encourage such practices, the guidelines award double points for increasing SEER if Manual S and D and start-up procedures are followed.

For cooling-dominated climates, it often makes sense to invest energy efficiency dollars in high SEER equipment. For climates with little cooling load, investments in efficiency may be better spent elsewhere.

Resources:

List of most energy efficient appliances
http://www.aceee.org/consumerguide/mostenef.htm

http://www.energystar.gov for a list of equipment meeting ENERGY STAR standards

H. Heat pump efficiency (heating mode)

1. 7.2-7.9 HSPF (6%-16% increase in efficiency)
2. 8.0-8.9 HSPF (18%-31% increase in efficiency)
3. 9.0-10.5 HSPF (32%-54%% increase in efficiency)
4. >10.5 HSPF (>54% increase in efficiency)

Intent:

To reduce the amount of nonrenewable energy used to meet the space heating requirements of a home.

Information / How to Implement:

Select equipment that carries the ENERGY STAR label, or check manufacturer's literature for HSPF data. The ACEEE lists the highest efficiency equipment available (see Resources). The current federal minimum Heating Season Performance Factor (HSPF), the standard measure of heat pump efficiency in the heating mode, is 6.8. Heat pumps are often the cost-effective solution for space conditioning equipment in climates where outdoor temperatures are moderate and there is a need for both heating and cooling. Air-to-air heat pumps are not recommended if winter temperatures often drop below 35° F. If heating is the predominant load, consider a heat pump with an HSPF of 8.0 or higher.

Resources:

- American Council for an Energy-Efficient Economy's list of most energy efficient appliances http://www.aceee.org/consumerguide/mostenef.htm
- http://www.energystar.gov for a list of equipment meeting ENERGY STAR standards

I Ground source heat pump installed by a Certified Geothermal Service Contractor. (cooling mode)

1. EER = 13-14
2. EER = 15-18
3. EER = 19-24
4. EER = > 25

Note: Additional 3 points are given if Manual S and D and start-up procedures are followed when one of the ground source heat pumps noted above has been installed. Do not duplicate points if these additional points have been taken in guidelines 3.3.2.f and 3.3.2.h above.

Intent:

To reduce consumption of non-renewable energy for space heating and cooling requirements and ensure that design and installation are conducted according to industry standards.

Information / How to Implement:

Select ENERGY STAR -labeled equipment or check manufacturer's literature for EER information. Use a contractor that has been certified in design and installation of geothermal systems by the International Ground Source Heat Pump Association (see Resources)—proper sizing of geothermal systems is crucial for efficiency and to reduce first cost. Ground source heat pumps are often more efficient than air-to-air heat pumps because they take advantage of the constant and more moderate temperature of the ground which is an advantage for space heating in the winter and cooling in the summer. Ground source heat pumps are more expensive to install than air-to-air heat pumps due to the added cost of drilling wells or trenching for the ground loop. However, they may be cost competitive when compared with very high efficiency furnaces and central air conditioning systems. Geothermal systems may also include a desuperheater, a device that uses some of the waste energy from the heat pump to pre-heat water for domestic use.

Because the selection of equipment, design of ductwork, and commissioning are integral to efficient performance of the system, additional points will be given if these measures have also been completed.

Resources:

- American Council for an Energy-Efficient Economy's list of most energy efficient appliances http://www.aceee.org/consumerguide/mostenef.htm
- http://www.energystar.gov for a list of equipment meeting ENERGY STAR standards
- International Ground Source Heat Pump Association (IGSHPA), database of accredited installers and designers of geothermal heat pump systems: http://www.igshpa.okstate.edu/business_directory/home.html

J. Ground Source Heat Pump installed by a Certified Geothermal Service Contractor (heating mode)

1. COP = 2.4-2.6
2. COP = 2.7-2.9
3. COP > 3.0

(See Section 3.3.2.I above for more information).

K. Seal ducts, plenums, and equipment to reduce leakage. Use UL 181 foil tapes and/or mastic.

Intent:

To assure optimum performance of the forced air space conditioning system by reducing duct leakage.

Information / How to Implement:

Duct leakage can reduce the heating and cooling efficiency of a forced air system by as much as 30%. While duct leakage to the conditioned space does not compromise energy performance as does duct leakage into unconditioned spaces, it may result in a less comfortable space due to insufficient air delivery. Best industry practice is to seal all ductwork with a foil tape meeting UL 181 requirements or with mastic. It is also important to seal plenum connections at the equipment as well as holes in the fan cabinet. Gasketed cabinet doors allow for a tight seal at this location without compromising ease of maintenance. An achievable goal is to strive for less than 5% leakage (as a percentage of the air handler capacity) to unconditioned space.

Resources:

- Air Distribution System Installation and Sealing, (U.S. DOE fact sheet), http://www.toolbase.org/docs/MainNav/Energy/4071_doe_airdistributionsysteminstallation.pdf
- Source of supply for duct mastic: Oikos.com has a list of manufacturers of Duct Mastic (category 15816)
- Advanced Air Sealing (book available for viewing online): http://oikos.com/library/airsealing/index.html
- Overview of sealing ductwork: http://energyoutlet.com/res/ducts/index.html

L. When installing ductwork:

1. No building cavities used as ductwork, e.g., panning joist or stud cavities.
2. Installation of all heating and cooling ducts and mechanical equipment within the conditioned building envelope.
3. No ductwork installed in exterior walls.

Intent:

The possibility of duct leakage to unconditioned space is significantly reduced by avoiding placement of ducts in areas listed.

Information / How to Implement:

Panned joists or stud cavities should be avoided because they can rarely be effectively sealed. When cavities are used as returns, air may be pulled from unintended locations in the home and create unwanted pressure imbalances that may compound energy loss. When cavities are used as supplies, the volume of delivered air may be inadequate and, because these areas may be dusty and dirty, *Indoor Environmental Quality* issues may result.

Methods for keeping ductwork in the conditioned envelope include extending the thermal boundary by insulating the foundation walls, insulating the attic at the roof, or installing ductwork beneath an insulated ceiling and enclosing it with bulkheads.

With improved window technology and air sealing practices, there is less need to supply warm air along exterior walls—a common practice in older homes that needed airflow near windows to prevent condensation on poorly insulating windows and to keep occupants warm near drafty windows. In tightly sealed and well-insulated homes, heating or cooling registers can be located near the interior, thereby minimizing duct length and eliminating any need to run ductwork in outside walls. This not only reduces duct leakage to the exterior but also eliminates the need to reduce insulation in those wall cavities.

Resources:

A Builder's Guide to Placement of Ducts and HVAC Equipment in Conditioned Space, 2000, NAHB Research Center. Available to purchase at http://www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2570&CategoryID=110

M. Install return ducts or transfer grilles in every room having a door except baths, kitchens, closets, pantries, and laundry rooms.

Intent:

To prevent pressure imbalances that may occur when there are central return(s) and interior doors are closed. Pressure imbalances can lead to inadequate airflow to a room which can create uncomfortable conditions.

Information / How to Implement:

Supply and return registers located in every room and sized according to industry standards provide the best assurance that airflow to each room is balanced. However, having supply and return vents in each room increases the installation cost of a forced air heating or cooling system. Common practice is to locate a single central return on each floor of the home. This method pulls return air from all areas of the home in most cases, but return airflow is restricted when doors are closed. Doors cannot be undercut sufficiently to provide an adequate path for air flow. When return air flow is restricted from a particular room, that area becomes pressurized and air leakage to the outdoors increases. Other areas of the home may become depressurized causing the opposite effect, i.e., outdoor air is drawn through cracks and crevices. Transfer grilles in interior walls are a cost effective compromise to ensuring that all rooms have adequate supply and return airflow.

Resources:

- ACCA Manual D® Residential Duct Systems

N. Install ENERGY STAR ceiling fans. (Points per fan.)

Intent:

To reduce energy use for space cooling while maintaining comfort.

Information / How to Implement:

A ceiling fan helps occupants feel cooler without lowering a thermostat because it provides convective cooling (the breeze created). Under many conditions, ceiling fans, which use less energy than most light bulbs, will be all that is required to keep occupants cool, thereby reducing the need for compressor cooling. ENERGY STAR fans produce more airflow per watt than standard ceiling fans due to improved blade design and more efficient motors.

Resources:

- ❖ List of ENERGY STAR labeled ceiling fans (fan only) http://www.energystar.gov/ia/products/prod_lists/ceiling_fans_only_prod_list.pdf
- ❖ List of ENERGY STAR labeled ceiling fans (fan and light) http://www.energystar.gov/ia/products/prod_lists/ceiling_fans_with_lighting_prod_list.pdf
- ❖ List of ENERGY STAR labeled ceiling fan (light kits only) http://www.energystar.gov/ia/products/prod_lists/ceiling_fans_lightkit_prod_list.pdf

O. Install whole-house fan with insulated louvers.

Intent:

To reduce energy use for space cooling while maintaining comfort.

Information / How to Implement:

A whole-house fan can draw outdoor air inside quickly, providing cooling at night and other times when the outdoor air is cooler than indoors. A whole house fan can reduce the energy needed for cooling by taking advantage of the "free" cooling from outside air. Whole house fans, usually placed in the ceiling of the top floor of a home, use less energy than a compressor and air handler to provide an efficient means of maintaining comfort during periods when outdoor air is cooler than indoor air. One disadvantage of whole house fans is that they can be difficult to seal off when not in use. Care must be taken in selecting equipment that has an effective insulating enclosure or in designing and installing a custom insulating and weather-stripping system for the enclosure.

Resources:

- ❖ *Home Energy Magazine* article http://hem.dis.anl.gov/eehem/99/990511.html
- ❖ *Whole House Fan: How to install and use a whole house fan*, http://www.southface.org/web/resources&services/publications/technical_bulletins/WHF-Wholehousefan%2099-745.pdf

P. Install ENERGY STAR labeled mechanical exhaust from every bathroom ducted to the outside.

Intent:

To achieve spot exhaust ventilation using highly-efficient ventilation equipment.

Information / How to Implement:

ENERGY STAR labeled fans provide more ventilation capacity at a lower wattage than a standard bath fan. They are also quieter than most standard fans and, therefore, are more likely to be used. Because of their more efficient blade design and motors, they are more durable and carry longer warranties than standard fans. Most major manufacturers offer an ENERGY STAR model but, in some areas, it may be a special order item.

This guideline also has an Indoor Environmental Quality benefit in that local removal of moisture and humidity is achieved in a more effective and efficient manner.

Resources:

- List of products meeting ENERGY STAR criteria: http://www.energystar.gov/ia/products/prod_lists/vent_fans_prod_list.pdf
- *Spot Ventilation: Source control to improve indoor air quality* (U.S. DOE fact sheet), http://www.toolbase.org/docs/MainNav/Energy/3947_spotventilation1.pdf

3.3.3. Water heating design, equipment, and installation

A Water heater Energy Factor equal to or greater than those listed in the following table.

Gas	
Size (gallons)	Energy Factor
30	0.64
40	0.62
50	0.60
65	0.58
75	0.56
Electric	
Size (gallons)	Energy Factor
30	0.95
40	0.94
50	0.92
65	0.90
80	0.88
100	0.86
Oil	
Size (gallons)	Energy Factor
30	0.59
50	0.55

Intent:

To increase the efficiency of water heating by installing equipment that provides the same amount of hot water for less energy than standard water heating equipment.

Information / How to Implement:

The hot water heater energy rating that is used to compare different water heaters is the Energy Factor (EF). EF represents the percentage of purchased fuel (electricity, gas, propane or oil) that is useful for heating water; it includes losses through the tank as well as flue losses. Electric tanks have a higher EF than fuel-fired heaters since they do not have flue losses. However, electric tanks can be more expensive to operate than fuel-fired tanks.

The hot water heater energy rating that is used to compare different water heaters is the Energy Factor (EF). EF represents the percentage of purchased fuel (electricity, gas, propane or oil) that is useful for heating water; it includes losses through the tank as well as flue losses. Electric tanks have a higher EF than fuel-fired heaters since they do not have flue losses. However, electric tanks can be more expensive to operate than fuel-fired tanks.

To select high efficiency water heating equipment, compare the yellow Energy Guide labels of similar equipment. Review manufacturer's literature for Energy Factor information—the EF is not usually prominently displayed on the unit. Alternately, the ACEEE maintains a list of the highest efficiency water heating equipment (see Resources).

Resources:

- *The Most Energy Efficient Appliances*, (list from Consumer's Guide to Home Energy Savings), American Council for an Energy Efficient Economy, http://www.aceee.org/consumerguide/mostenef.htm
- *Gas Appliance Manufacturer's Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment.* www.gamanet.org
- *Water Heating: Energy-Efficient Strategies for Supplying Hot Water in the Home* (U.S. DOE fact sheet), http://www.toolbase.org/docs/SubsystemNav/Plumbing/3946_waterheating.pdf

B. Install whole house instantaneous (tankless) water heater. (Water heater complies with DOE Standard 10CFR430)

Intent:

To reduce energy use associated with water heating by eliminating standby losses that occur with tank heaters.

Information / How to Implement:

Even though newer tank water heaters are better insulated than their predecessors, heat lost from a water heater tank can account for a large portion of hot water energy consumption, especially in homes that use relatively little hot water. By having no reservoir of hot water, tankless water heaters eliminate these standby losses. For gas tankless water heaters, there are similar flue losses to gas tanks. Both electric and gas tankless water heaters have higher energy factors (EF = 0.62 minimum) than most tank water heaters

Gas, propane, and electric instantaneous water heaters are available. Typically, gas water heaters can heat a larger volume of water each minute than electric heaters and can provide a greater temperature rise for a given flow rate. This can be an important consideration when coincident hot water uses are expected or when high flow rates at hot temperatures are desired. Electric tankless units can achieve about a 77°F temperature rise at 2.5 gallons per minute–which is plenty for a hot shower but it does not leave a lot of extra capacity for simultaneous hot water usage. Gas units will provide greater capacity to allow for simultaneous multiple uses.

All tankless water heaters use large amounts of energy at higher flow rates. These large draws often require a larger-than-normal service entrance for electric units or larger pipe diameter for gas units. Evaluate these differences when comparing installed costs and check with local utilities regarding issues related to peak demand. Although peak demand for space heating and water heating usually do not occur at similar times, your local utility may offer helpful advice regarding selection of whole house water heating appliances.

Resources:

- *The Most Energy Efficient Appliances,* (list from Consumer's Guide to Home Energy Savings), American Council for an Energy Efficient Economy, http://www.aceee.org/consumerguide/mostenef.htm

C. Insulate all hot water lines with a minimum of 1" insulation.

Intent:

To reduce energy losses from hot water piping.

Information / How to Implement:

Benefit from insulating hot water piping can be gained in two ways: 1) losses are reduced as hot water moves through the lines to the point of use, and 2) losses are slowed and may be reduced when hot water sits in the lines between draws. Foam pipe insulation is relatively inexpensive and easy to install. In addition to offering some energy savings, insulating the hot water lines is also likely to add convenience, comfort, and water savings. Hot water will get to the tap more quickly – a benefit for the user and less potential to let water run down the drain waiting for it to get hot.

Resources:

- *Water Heating: Energy-Efficient Strategies for Supplying Hot Water in the Home* (U.S. DOE fact sheet), http://www.toolbase.org/docs/SubsystemNav/Plumbing/3946_waterheating.pdf

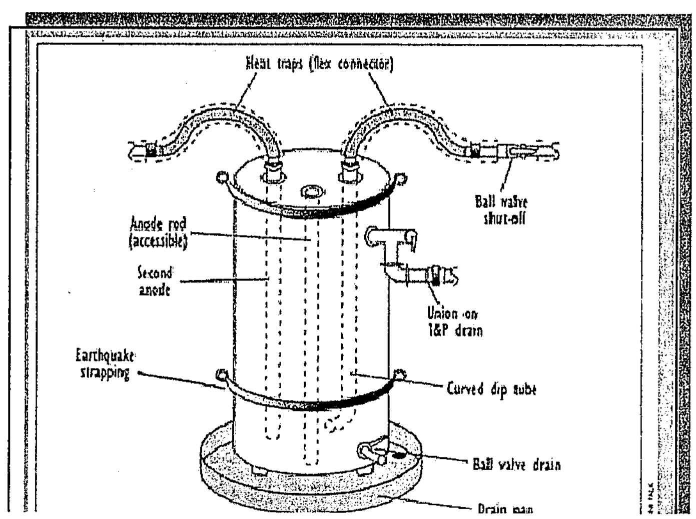
D. Install heat trap on cold and hot water lines to and from the water heater (if not integral to the water heater).

Intent:

To minimize energy loss associated with thermo siphoning action from a water heater.

Information / How to Implement:

In the same way that warm air moves towards cooler air and that warm air rises, hot water in a water heater tank will rise and displace cooler water in the lines leading to and from the tank. This thermo siphoning action contributes to heat loss from the tank and, once



Schematic of a water heater. Note the heat traps, made by bending the flex connectors into an inverted U shape.

the water temperature in the tank has cooled below the thermostat set point, the elements or burner will need to activate to bring the water back up to temperature–even when there is no demand for hot water. Heat traps prevent thermo siphoning. Many new water heaters have integral heat traps; ask your plumber or plumbing material supplier which water heaters have integral heat traps, or check manufacturer's literature. If heat traps are not integral to the water heater, install them on the inlet and outlet to the water heater.

Resources:

- *Water Heating: Energy-Efficient Strategies for Supplying Hot Water in the Home* (U.S. DOE fact sheet),

E. Install manifold plumbing system with parallel piping configuration (aka "home run") using smallest diameter piping allowed by code.

Intent:

Reduce energy use associated with waiting for hot water at taps and with hot water left standing in pipes after a hot water draw.

Information / How to Implement:

A manifold plumbing system, in which dedicated "home run" hot and cold water piping services each fixture, allows the most direct (and therefore shortest) pipe run and smaller diameter piping serving each fixture than a "tree" type piping configuration. Reduced pipe diameter means hot water is delivered faster to a faucet and that there is less water left in a pipe after a hot water draw—and therefore less energy waste from hot water left to cool in pipes. Most manifold piping is cross-linked polyethylene (PEX) pipe rather than copper or CPVC. Because PEX allows for gentle bends, fittings are reduced which saves installation time and minimizes the possibility of leaks. Often, 3/8" diameter pipe can be used. PEX pipe also has better insulating value than copper piping. In order to maximize the benefits of a manifold system, baths and kitchens should be located in close proximity to one another and to the water heater.

Resources:

Information will be added in Version 2.

3.3.4. Lighting and Appliances

A. Use an ENERGY STAR Advanced Lighting Package (ALP).

Intent:

To meet electric lighting needs with high-quality, aesthetically pleasing light using less energy than conventional incandescent lighting.

Information / How to Implement:

ENERGY STAR fixtures use about 2/3 less electricity than standard fixtures to provide equal light. Although, on average, an ENERGY STAR fixture may cost about $30 more than a comparable standard fixture, the fluorescent bulbs will last longer (on average about 7 years) and cost less to operate over their lifetime than incandescent bulbs. Placing 20 ENERGY STAR fixtures in a home in which electricity costs are

10.5 cents per kWh will reap almost $100 in annual savings to the homeowner in energy and bulb replacement costs, after accounting for the increase in the mortgage due to higher initial cost. Today's fluorescent bulbs are dramatically improved over the old technology: not only are a wide variety of styles available, but the light quality is high and there is no flicker, hum, or delayed start. ENERGY STAR fixtures also carry a two-year warranty. The fixtures may be easily identified by the ENERGY STAR label.

Room Category	Specific Rooms within Category	Minimum Percentage of Required ENERGY STAR Qualified Fixtures per Room Category
High-Use Rooms	Kitchen, Dining Room, Living Room, Family Room, Bathroom(s), Halls/Stairway(s)	50% of Total Number of Fixtures
Med/Low-Use Rooms	Bedroom, Den, Office, Basement, Laundry Room, Garage, Closet(s), and All Other Rooms	25% of Total Number of Fixtures
Outdoors	Outdoor Lighting Affixed to Home or Free-Standing Pole(s) except for landscape and solar lighting	50% of Total Number of Fixtures including all flood lighting

Resources:

Tool to estimate lighting energy savings of Advanced Lighting Package:
http://www.energystar.gov/ia/partners/manuf_res/Savings_Look-up_ChartsLR.pdf

ENERGY STAR Program information for builders:
http://www.energystar.gov/index.cfm?c=bldrs_lenders_raters.ALP_Builder

B. Install all recessed lighting fixtures within the conditioned envelope of the building, e.g., housing does not penetrate insulated ceiling.

Intent:

To eliminate energy losses associated with inadequate insulation above, and air infiltration through, light fixtures in insulated ceilings.

Information / How to Implement:

Although there are recessed light fixtures rated for insulation contact, they still carry an energy penalty because of reduced insulation thickness in the ceiling above the fixture and/or air leakage around the housing. To completely avoid this energy penalty, do not install recessed lights in an insulated ceiling. Bulkheads or dropped soffits can permit the installation of recessed lights in insulated ceilings. Be sure that there is a continuous air barrier at the top of the bulkhead or the original ceiling. The preferred method is to install drywall (or other finish material) on the ceiling prior to constructing the bulkhead.

Resources:

Information will be added in Version 2.

C. Install motion sensors on outdoor lighting (if not credited under 3.3.4.a).

Intent:

To minimize outdoor lighting energy use by activating outdoor lighting when it is needed, rather than operating it continuously.

Information / How to Implement:

Motion sensors activate outdoor lighting only when it is needed, for instance to light an entry as one returns home after dark or to maintain security by illuminating outdoor areas when motion is detected. Many fixtures come with motion sensors, but motion sensors can also be installed separately. Not all outdoor ENERGY STAR fixtures have built-in motion sensors.

Resources:

Information will be added in Version 2.

D. Install tubular skylights in rooms without windows.

Intent:

To reduce the need for artificial lighting by providing natural light when available.

Information / How to Implement:

Tubular skylights provide natural lighting to interior spaces while minimizing the inherent energy losses of standard skylights. Tubular skylights have a smaller diameter roof penetration than most skylights and have an additional layer of insulating glazing at the ceiling level.

Resources:

Tubular Skylights (NAHB Research Center technology fact sheet)
http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1282&DocumentID=2024.

E. Install ENERGY STAR labeled appliance: Refrigerator, dishwasher, washing machine. (Points per appliance.)

Intent:

To reduce energy use in the home for appliances.

Information / How to Implement:

On average, ENERGY STAR labeled appliances use at least 20% less energy than standard appliances to perform the same duties. ENERGY STAR labeled dishwashers and washing machines also use less water, which contributes to added resource efficiency. Look for the ENERGY STAR label when selecting major appliances or use the yellow EnergyGuide label to compare efficiency of similar appliances.

If you are not directly responsible for the purchase and installation of appliances, you can help customers learn about ENERGY STAR options. It is recommended that points be awarded only if ENERGY STAR appliances are actually installed in the home at the time a project is certified.

Resources:

- http://www.energystar.gov for list of appliances meeting ENERGY STAR criteria and list of local stores that sell ENERGY STAR appliances. The Website also includes a calculator to show prospective homeowners how much they will save and how fast the upgraded appliance will pay for itself over time.

3.3.5 Renewable Energy/Solar Heating and Cooling

3.3.5.1. Solar Space Heating and Cooling

More detailed design guidance for climate-specific passive solar design is available from the Sustainable Building Industry Council , 1331 H Street NW, Suite 1000, Washington, DC 20005; Phone: (202) 628-7400; www.sbicouncil.org.

A. Use sun-tempered design: Building orientation, sizing of glazing, design of overhangs to provide shading are in accordance with guidelines below*:

- Long side of the home faces within 30° of south;
- Glazing area < 7% of Finished Floor Area (FFA) on south face (Low-E);
- Glazing area < 2% of FFA on west face (Low-E, Low SHGC);
- Glazing area < 4% of FFA on east face (Low-E, Low SHGC);
- Glazing area < 4% of FFA on north face (Low-E);
- Skylights less than 2% of finished ceiling area, with shades and insulated wells;
- Overhangs designed to provide shading on south-facing glass (at a minimum), or adjustable canopies or awnings. (See Users' Guide for charts that indicate length of overhang, amount and period of shading according to latitude.)

Intent:

To reduce the amount of non-renewable energy required to heat and cool a home through design features which permit solar heat gains and minimize the potential for overheating.

Information / How to Implement:

The Sustainable Buildings Industry Council provides the most concise and clear-cut guidance on sun-tempered design. The design rules of thumb cited above will provide some solar benefit and prevent overheating in most climates.

Resources:

- Green Building Guidelines – Meeting the Demand for Low-Energy, Resource-Efficient Homes, Chapter 2A: Renewable Energy: Solar and Other Renewables, Sustainable Buildings Industry Council.
- *Passive Solar Design Strategies, Guidelines for Home Building*, Sustainable Building Industries Council, http://www.psic.org.

- *Passive Solar Design* (NAHB Research Center fact sheet) http://www.toolbase.org/docs/MainNav/Energy/3944_passivesolardesign.pdf

B. Use passive solar design: Sun-tempered design as above plus additional south-facing glazing, appropriately designed thermal mass to prevent overheating, and provision for air flow to adjoining rooms.

- ☐ Sun-tempered design as outlined in Section 3.3.5.1a except additional glazing permitted on south wall PLUS
- For any room with south-facing glazing > 7% of FFA, properly sized thermal mass, and
- Provision for forced air flow to adjoining areas as needed.
- (SBIC Passive Solar Design Guidelines for your climate should be referenced to size thermal mass.)

Intent:

To reduce the amount of non-renewable energy required to heat and cool a home by taking advantage of the sun's energy through passive design features that collect desirable solar heat gain and mitigate unwanted solar heat gain.

Information / How to Implement:

Note:3.3.5.1.A must also be implemented to receive points for 3.3.5.1.B.

In most regions of the country having a winter heating load, homes can be designed such that a portion of this load can be satisfied by solar gains. As south facing glass is increased to obtain greater solar benefit, thermal mass must be provided to store excess heat gain, prevent overheating, and moderate heat delivery to the home. Properly sized thermal mass (typically in the form of masonry materials such as tile floors and brick walls, or water) absorbs heat while the sun strikes it and releases that heat slowly once the sun has gone down. Designing a truly passive solar home requires careful calculation of solar gain, thermal storage capacity, and hourly outdoor winter conditions. Obtain the Passive Solar Design Guidelines (see Resource) for your climate as well as the other references cited below if you intend to build a passive solar home. It is also advisable to consult a design professional with background and experience in passive solar design.

Resources:

- *Green Building Guidelines – Meeting the Demand for Low-Energy, Resource-*Efficient Homes, Chapter 2A: Renewable Energy: Solar and Other Renewables, Sustainable Buildings Industry Council.
- Sustainable Building Industry Council Passive Solar Design Guidelines, available at http://ww.sbicouncil.org

C. Use passive cooling.

- Exterior shading on east and west windows, e.g., shade trees, moveable awnings or louvers, covered porches

- ❖ Overhangs designed to provide shading on south-facing glazing. (Use supplied charts that indicate length of overhang and amount and period of shading according to latitude.) (Not to be double-counted if credited in 3.4.1.a above)
- ❖ Windows located to facilitate cross ventilation.
- ❖ Solar reflective roof or radiant barrier in hot climate.

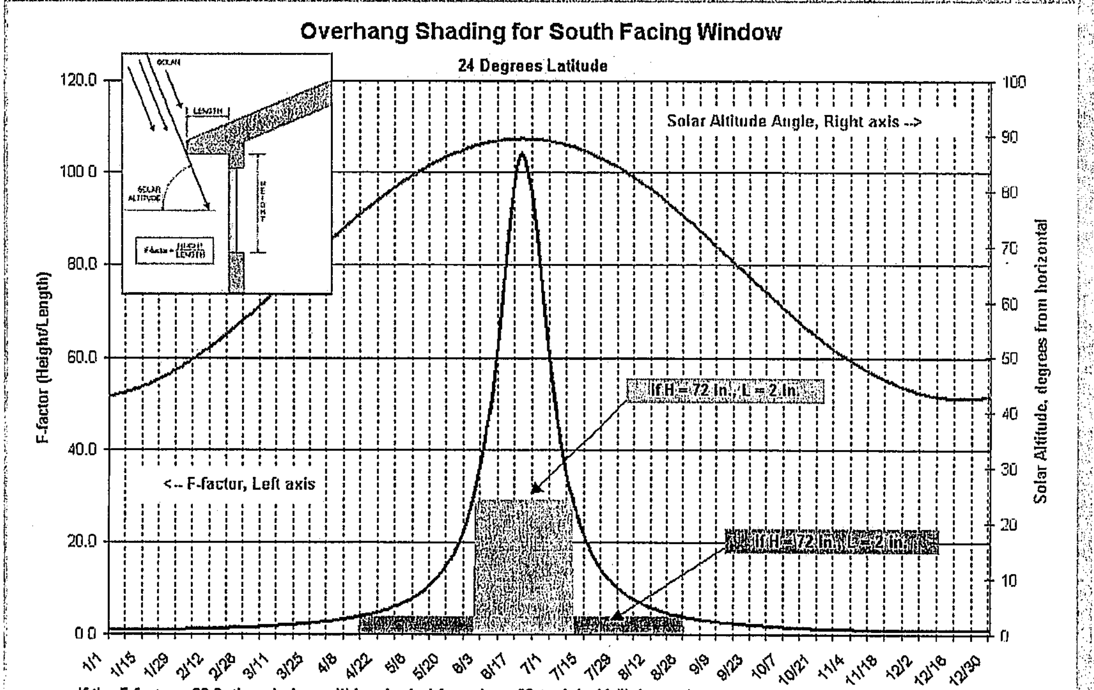
Intent:

To reduce non-renewable energy required for space cooling in the home by mitigating solar heat gain and using design features that promote natural ventilation.

Information / How to Implement:

Natural features, landscaping, and architectural features can help cool a home naturally and/or reduce unwanted solar gains that increase cooling load. The charts below provide guidance on the length of overhangs to achieve desired shading of south-facing glass for different latitudes in the country.

Shading of east and west windows is difficult to achieve with a fixed overhang because the sun is low in the sky when shading is typically desired. Moveable awnings or louvers allow the flexibility to shade windows during certain times of the day or year. In cooling-dominated climates, a covered porch may be a good solution on the west side of the home to mitigate unwanted solar heat gain.



If the F-factor = 29.2, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 3.8, the window will be shaded from April 16 to August 27 (dark grey)

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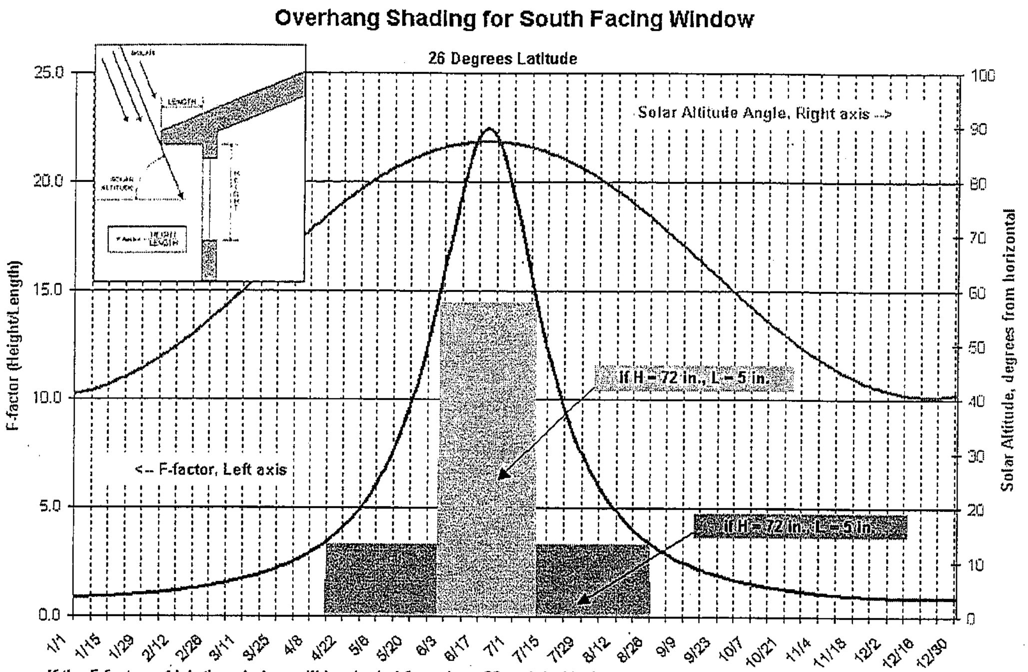
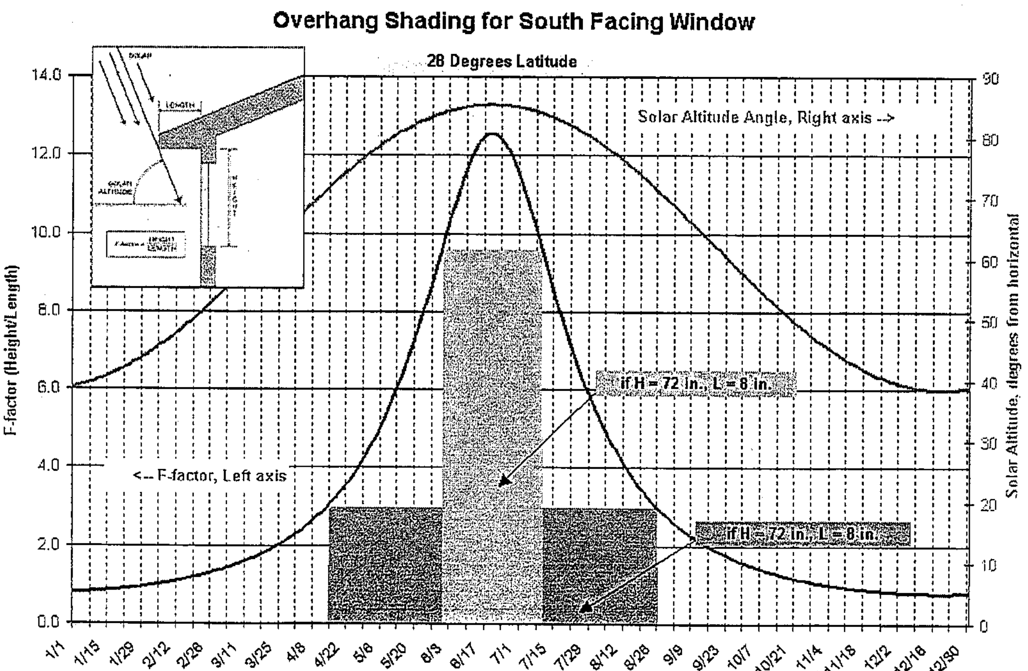
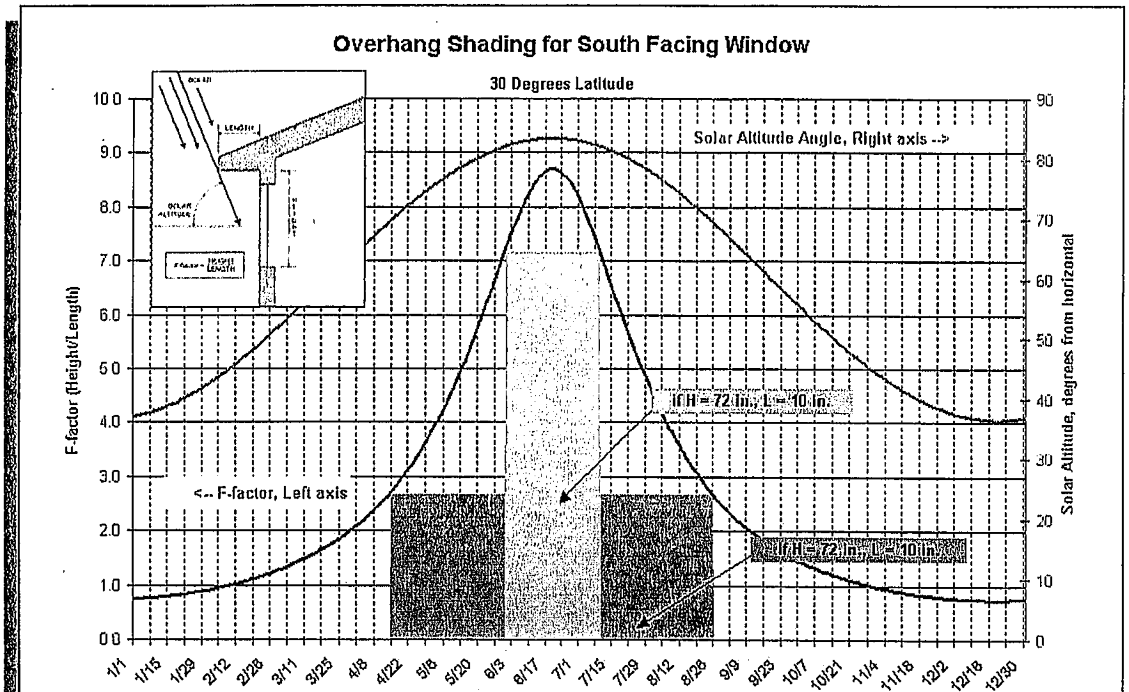


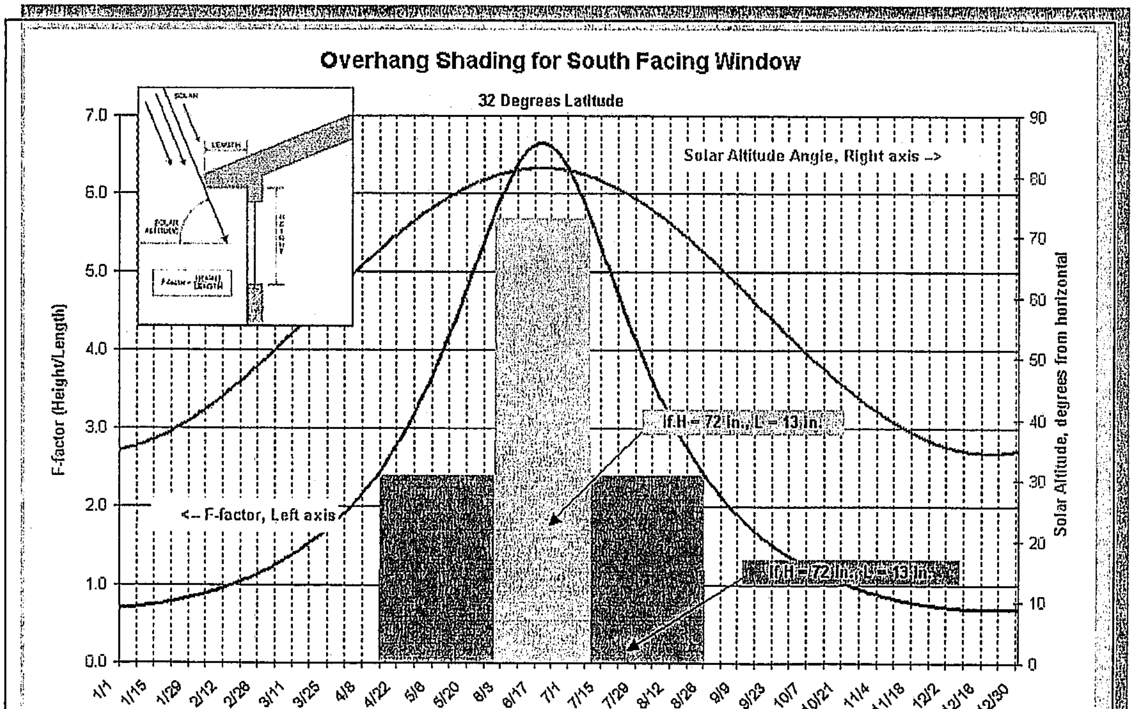
If the F-factor = 14.4, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 3.4, the window will be shaded from April 16 to August 27 (dark grey)



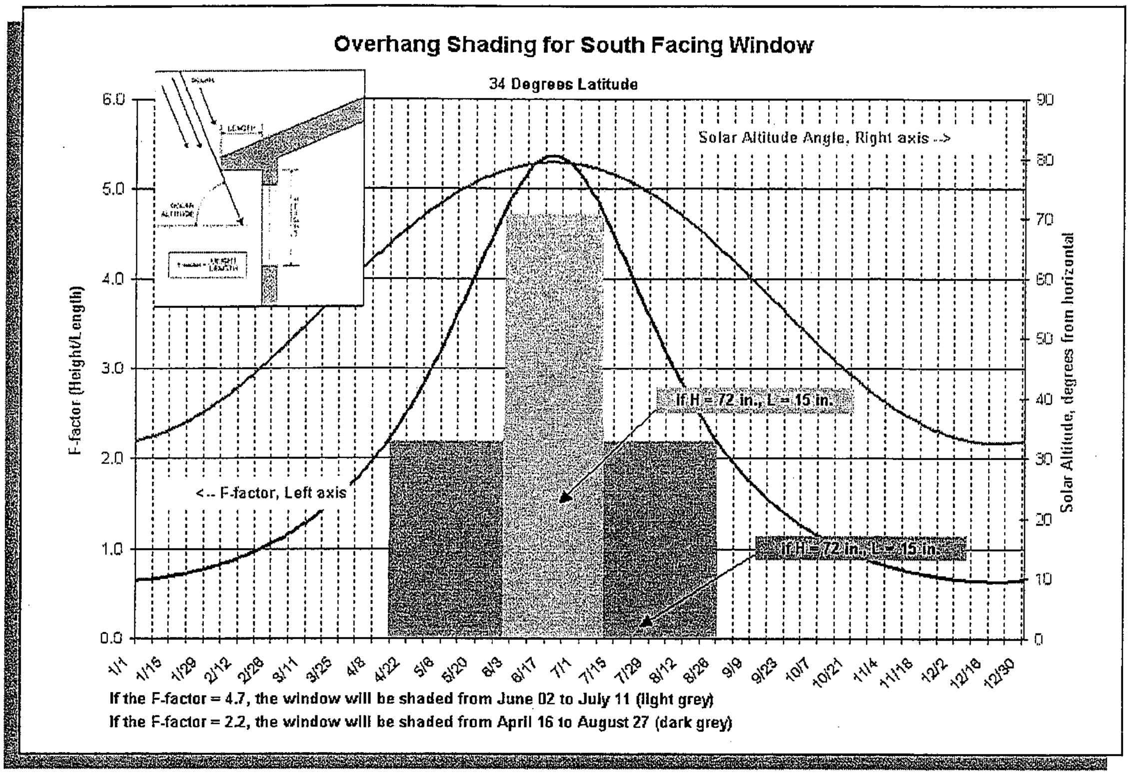
If the F-factor = 9.6, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 3.0, the window will be shaded from April 16 to August 27 (dark grey)

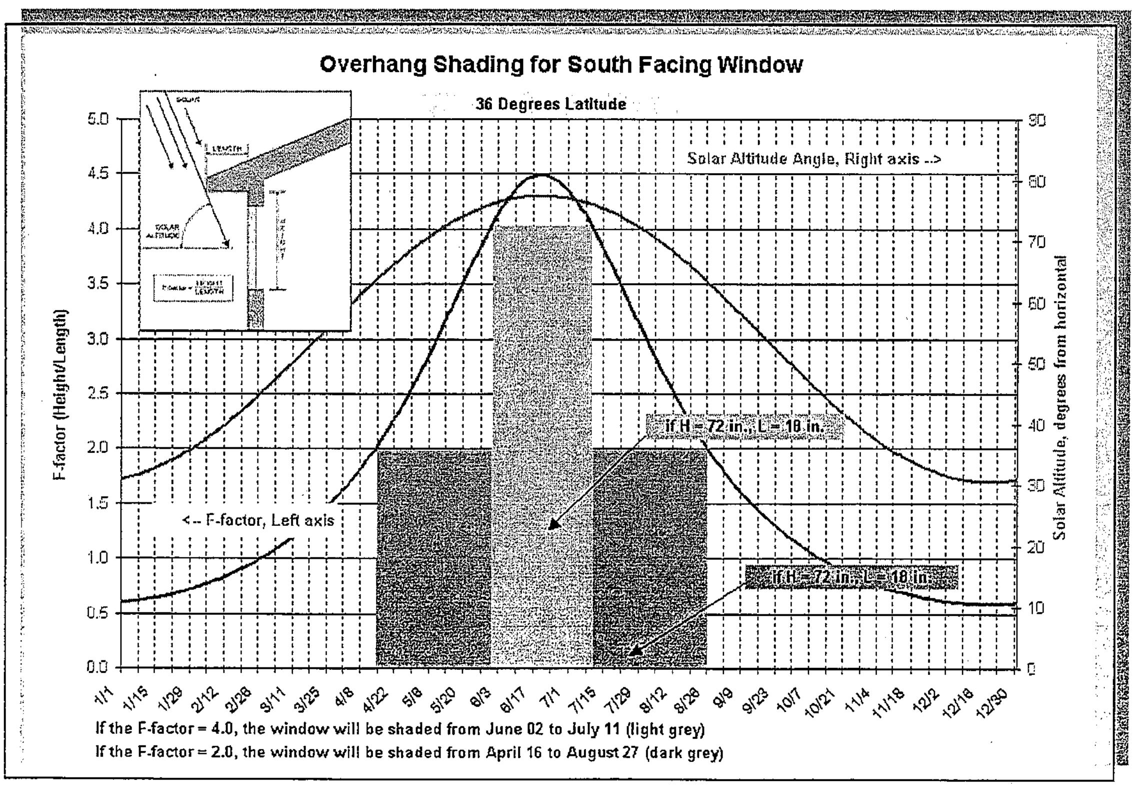


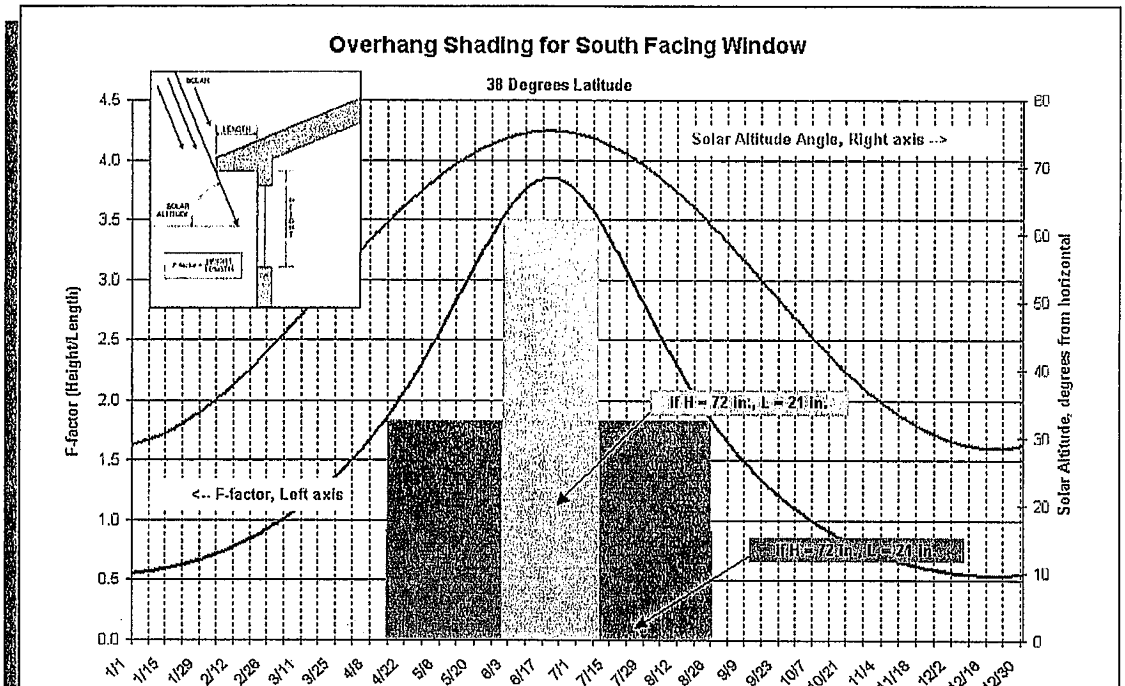
If the F-factor = 7.2, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 2.7, the window will be shaded from April 16 to August 27 (dark grey)



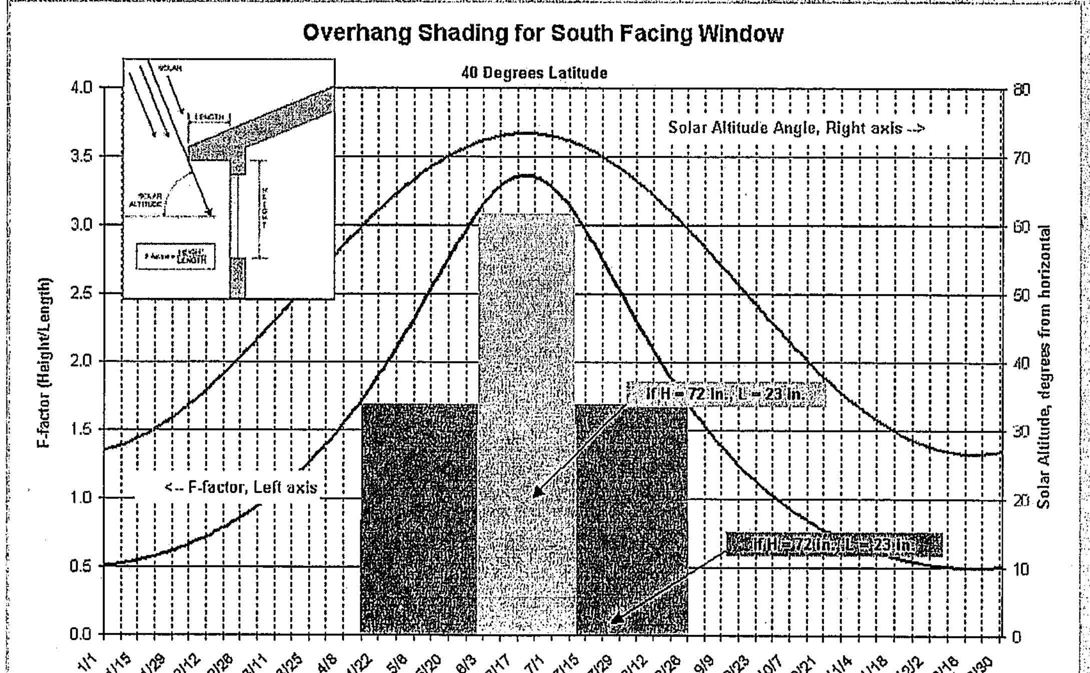
If the F-factor = 5.7, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 2.4, the window will be shaded from April 16 to August 27 (dark grey)


Overhang Shading for South Facing Window
34 Degrees Latitude
Solar Altitude Angle, Right axis -->
<-- F-factor, Left axis
If H = 72 in., L = 15 in.
If H = 72 in., L = 15 in.
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
If the F-factor = 4.7, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 2.2, the window will be shaded from April 16 to August 27 (dark grey)

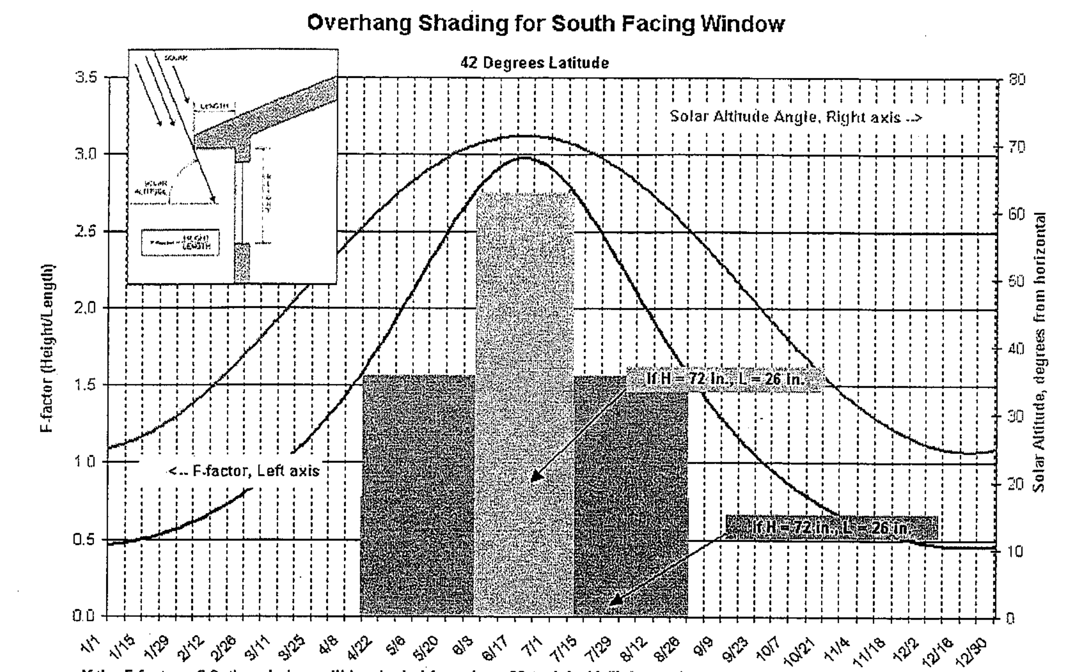

Overhang Shading for South Facing Window
36 Degrees Latitude
Solar Altitude Angle, Right axis -->
<-- F-factor, Left axis
If H = 72 in., L = 18 in.
If H = 72 in., L = 18 in.
F-factor (Height/Length)
Solar Altitude, degrees from horizontal
If the F-factor = 4.0, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 2.0, the window will be shaded from April 16 to August 27 (dark grey)



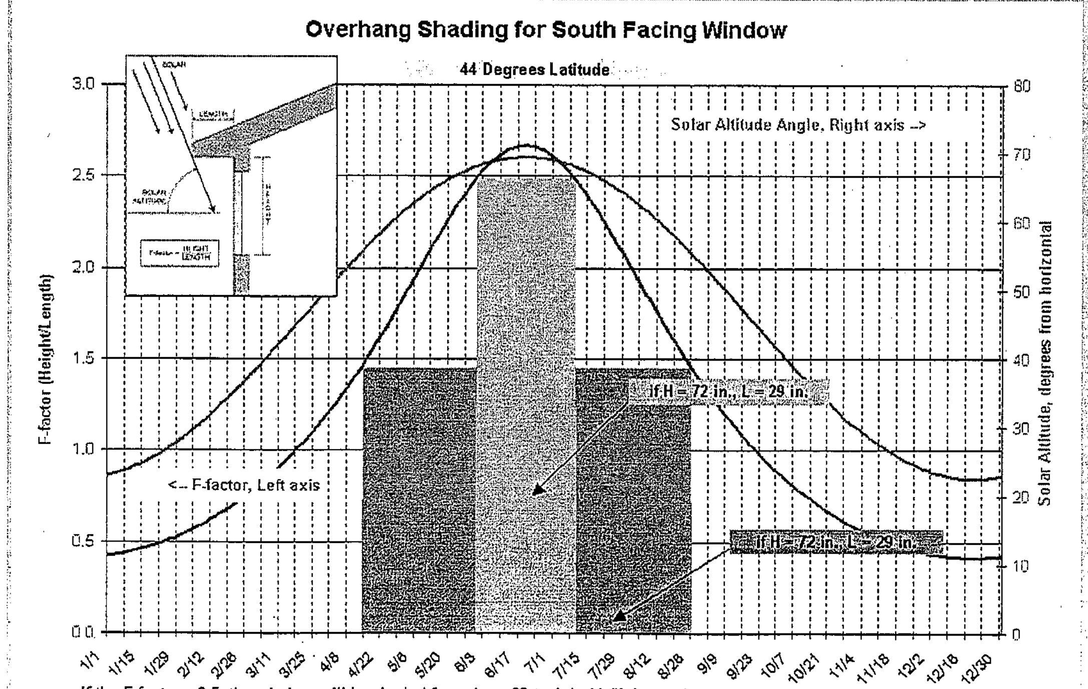
If the F-factor = 3.5, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.8, the window will be shaded from April 16 to August 27 (dark grey)



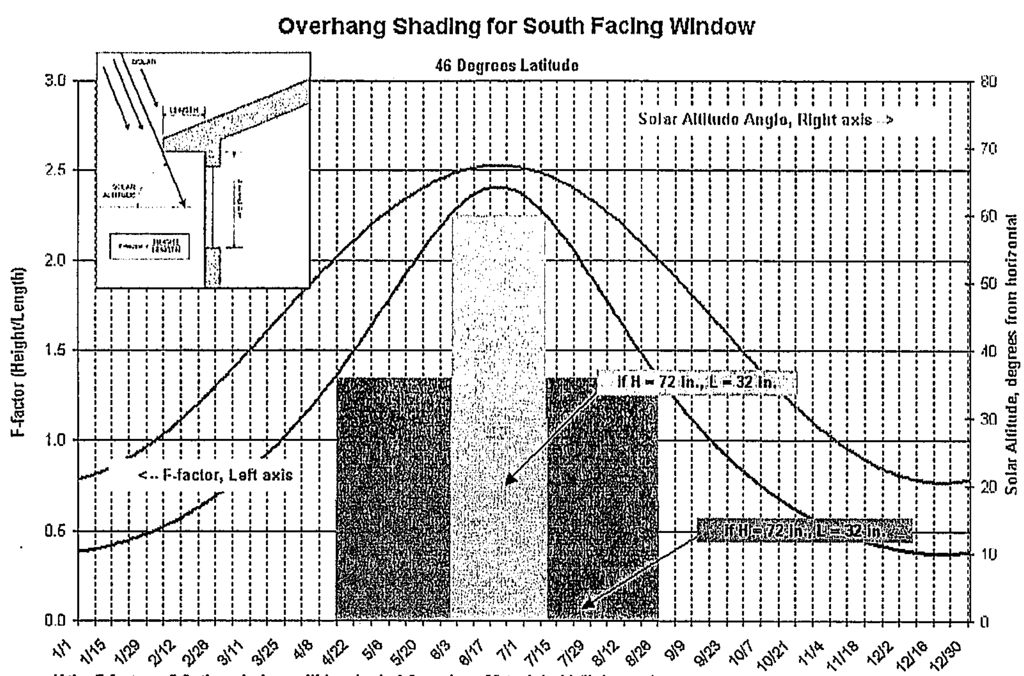
If the F-factor = 3.1, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.7, the window will be shaded from April 16 to August 27 (dark grey)



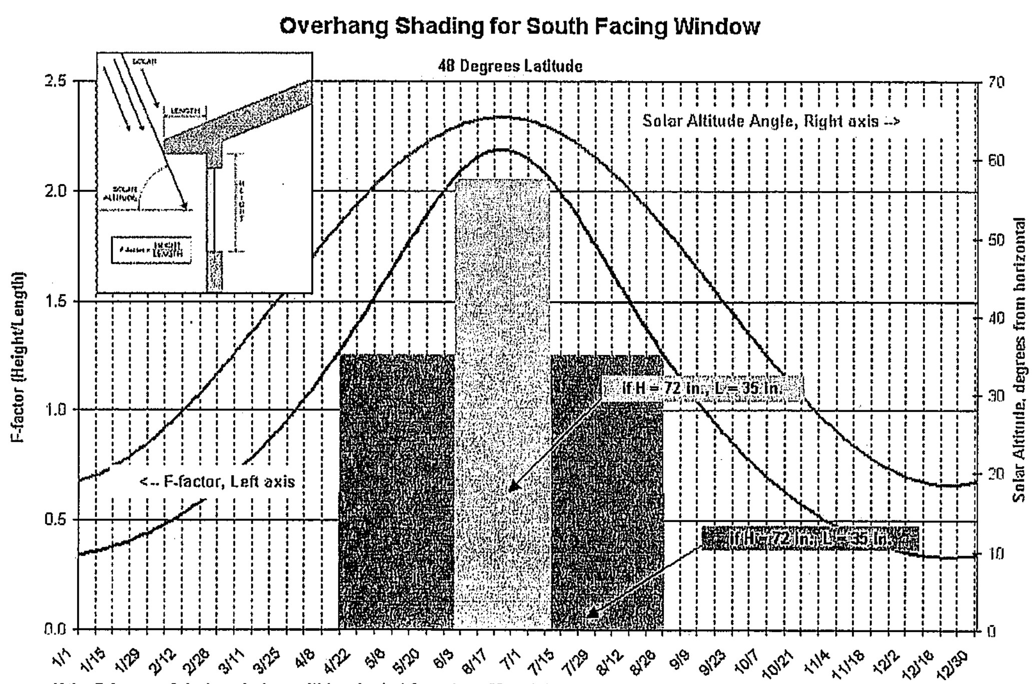
If the F-factor = 2.8, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.6, the window will be shaded from April 16 to August 27 (dark grey)



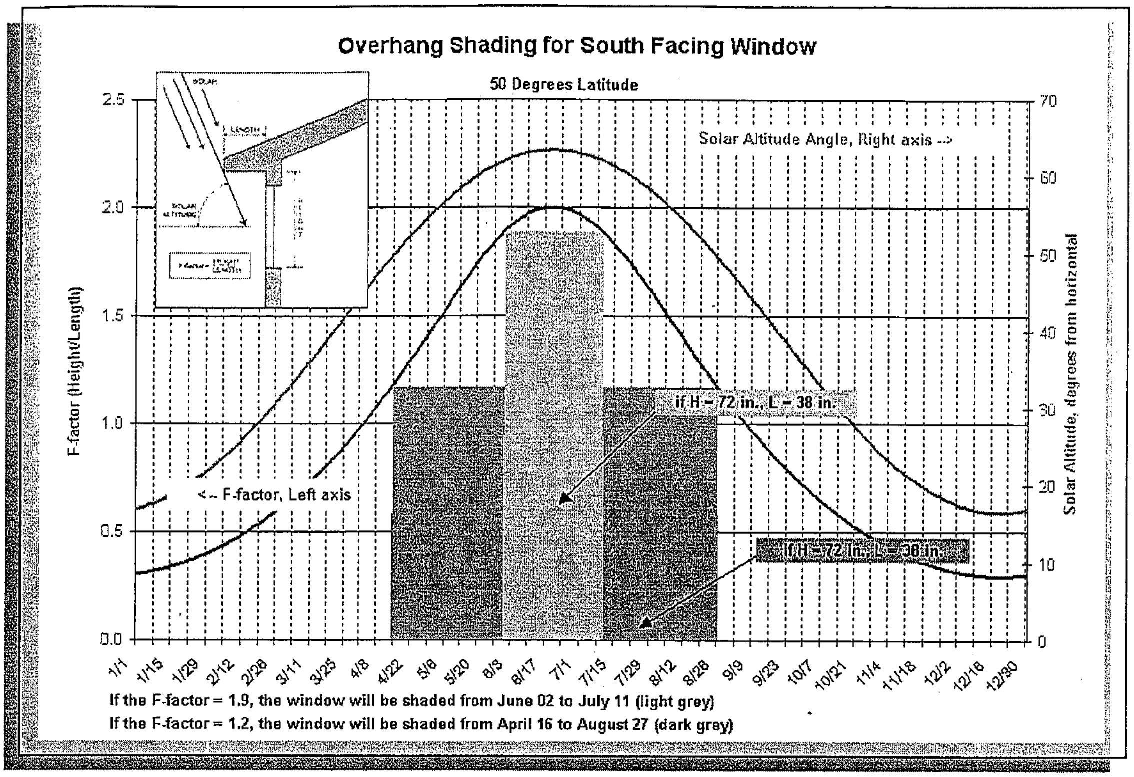
If the F-factor = 2.5, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.5, the window will be shaded from April 16 to August 27 (dark grey)



If the F-factor = 2.3, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.3, the window will be shaded from April 16 to August 27 (dark grey)



If the F-factor = 2.1, the window will be shaded from June 02 to July 11 (light grey)
If the F-factor = 1.3, the window will be shaded from April 16 to August 27 (dark grey)



Resources:

- *Passive Solar Heating and Cooling: Natural Cooling*, Arizona Solar Center fact sheet, http://www.azsolarcenter.com/technology/pas-3.html
- *Cooling Your Home Naturally*, (U.S. DOE fact sheet) http://www.eere.energy.gov/consumerinfo/pdfs/coolhome.pdf
- *Passive Solar Design Strategies*, Guidelines for Home Building, Sustainable Building Industries Council, www.psic.org.

3.3.5.2 Solar Water Heating

A. Install solar water heating system. Must use Solar Rating and Certification Corporation (SRCC)-rated system. Solar fraction:

1. 0.3
2. >0.5

Intent:

To reduce non-renewable energy use for domestic water heating.

Information / How to Implement:

Solar collectors that preheat water for domestic use are often cost effective. However, solar water heaters must be designed and installed properly to operate to their maximum potential for many years. Solar water heater designs are generally climate specific, primarily with regards to freeze protection. Consult a knowledgeable local installer to design the system, select equipment, and carefully install the system. Use the references below for a basic understanding of the types of systems available and the estimated performance in your climate. Use the ratings published by the SRCC (see Resources) to determine the solar fraction provided by the system you select.

Resources:

- For a list of Solar Rating and Certification Corporation's certified solar water heating systems, see www.solar-rating.org
- *Solar Water Heaters* (NAHB Research Center technology fact sheet), http://www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2136&CategoryID=68
- Database of State Incentives for Renewable Energy, www.dsireusa.org

3.3.5.3 Additional Renewable Energy Options

A. Supply electricity needs via onsite renewable energy source such as photovoltaic, wind or hydro whereby the system is estimated to produce the following kWh per year:

1. 2,000 to 3,999
2. 4,000 to 5,999
3. 6,000 +

(Equipment should carry all applicable IEEE and UL certifications. Installation shall be in accordance with local utility and electrical code requirements.)

Intent:

To supply a portion of a household's electricity needs by renewable energy sources. To reduce peak electricity demand of the home. Peak electricity demand can necessitate power companies to operate peak generation equipment which, because it is operated for a short time, generally is less efficient than non-peak power production.

Information / How to Implement:

As demand for electricity increases and costs to build additional generating capacity continue to escalate, renewable energy sources such as photovoltaics and wind power become more attractive and more cost effective to consumers and utilities. Local generation of electricity by the sun and wind is a viable option in most regions of the country. Costs of smaller (2 kW to 8 kW) photovoltaic systems are about $8-$9 per watt and, in some states like New York, California, and New Jersey, incentives are available which bring the cost even lower. Net metering—in which excess electricity produced at a residence causes the electric meter to spin backwards—may also be available in your area. Net metering effectively credits the customer full retail value for electricity sent back to the utility and greatly improves the economics of residential solar electric power production.

Resources:

- http://www.dsireusa.org - provides information about areas offering incentives that promote renewable energy and information about net metering rules.

B. Provide clear and un-shaded roof area (+/-30° of south or flat) for future solar collector or photovoltaics. Minimum area of 200 sf. Provide a rough-in of piping from the roof to the utility area for:

1. Conduit
2. Insulated piping

Intent:

To encourage and facilitate installation of renewable energy systems for space and water heating needs.

Information / How to Implement:

By providing the infrastructure for the installation of a solar thermal collector or photovoltaic system, you can increase the likelihood that the homeowner will install a renewable energy system in the future. Given the uncertainties of the cost of electricity as well as the possibility of eventual incentives, it makes energy and economic sense to build this flexibility into the home. It is relatively simple and inexpensive to run electrical conduit or water piping to the attic or roof area while the home is but can be disruptive and costly when retrofitted at a later date. This measure contributes to the cost effectiveness of the installation of a future renewable energy system.

Resources:

Information will be added in Version 2.

C. Provide homeowner with information and enrollment materials about options to purchase green power from the local electric utility. *(Not to duplicate points for Homeowner Manual in IEQ section below.)*

Intent:

To increase the possibility that the homeowner will select green power when available from the local utility.

Information / How to Implement:

Many utilities across the country purchase or produce at least some power from renewable sources such as wind or hydro. Some utilities are offering this power to their customers through green pricing programs. In a typical green pricing program, a customer can choose to purchase a certain amount of electricity generated by renewable sources. While this electricity is usually more expensive than the utility's standard rates, green pricing programs enable the customer to indicate their support for renewable energy sources.

Resources:

- http://www.eere.energy.gov/greenpower/markets/pricing.shtml?page=0
- Database of State Incentives for Renewable Energy, http://www.dsireusa.org/
- State Energy Office—directory of state energy offices at http://www.naseo.org/members/states.htm
- Photovoltaics, U.S. DOE fact sheet, http://www.eere.energy.gov/RE/solar_photovoltaics.html

3.3.6 Verification

3.3.6.1 Conduct onsite third party inspection to verify installation of energy related features such as:

A. Duct installation and sealing

B. Building envelope air sealing details

C. Proper installation of insulation including: no gaps, voids, or compression

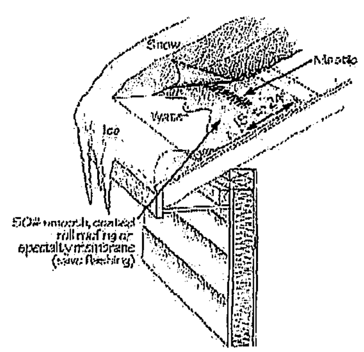
D. Batt insulation cut accurately to fit cavity.

E. Windows and doors flashed, caulked, and sealed properly.

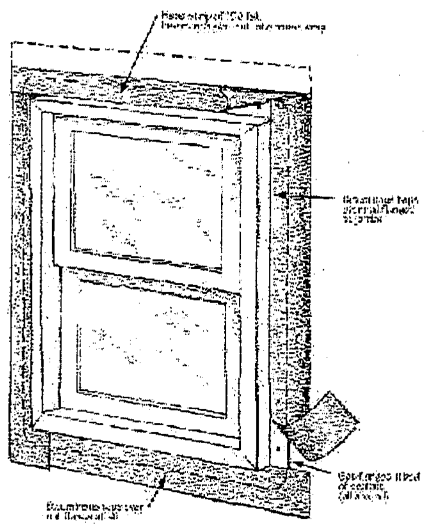
(When at least 100 homes of the same model are to be built by the same builder, a representative sample (15%) of homes may be inspected.)

Intent:

The third-party verification of materials and features that enhance energy efficiency offers customers an added level of assurance that the home will perform as designed. Most builders that have used third-party inspections say it is worth the extra cost because it provides proof to potential clients that the home has higher quality energy features than competitors' homes.



Ice Flashing Detail



Window Flashing Detail

Information / How to Implement:

A third-party inspection can be performed by any objective, experienced, outside party such as a green building program coordinator, a code enforcement official, an architect or engineer, an energy consultant or specialist, a Home Energy Rating System professional (HERS rater), or an energy program coordinator. Photographs taken by the builder during construction have often been used to defray costs associated with onsite inspections.

Resources:

- ❖ Third party plan review using a Certified HERS rater. A directory of Home Energy Raters can be found on the ENERGY STAR Website at http://www.energystar.gov.
- ❖ Local utility, if it offers a new home energy efficiency program.

3.3.6.2 Conduct third-party testing to verify performance, e.g., blower door, duct leakage, and flow hood testing (points given per test).

A. Building envelope leakage: blower door test results < 0.35 ACHnat

B. Central HVAC duct leakage: Duct leakage test results:

- Leakage to unconditioned space < 5% of rated blower capacity.
- Total leakage < 10% of rated blower capacity.

C. Balanced HVAC air flows: Flow hood test results:

- Measured flow at each supply and return register within 25% of design flow.
- Total air flow within 10% of design flow

(When multiple homes of the same model are to be built by the same builder, a representative sample of homes may be tested subject to the sampling protocol.)

Intent:

Testing of the installed systems of a home such as envelope or duct tightness or air flows of HVAC systems provides an added level of assurance to the customer as well as to the builder that energy features were installed properly and will perform to expected levels.

Information / How to Implement:

Keep in mind that proper design and installation are the key ingredients; testing is "the cream" that provides confirmation, assurance, and possibly education. With respect to blower door and duct blaster testing the builder is not only able to gain an idea of the relative tightness of the envelope or the ductwork, but can also identify potential problem areas that need correction. Duct blaster testing is less important when all ducts are located within conditioned space; under these conditions, the test may identify comfort or installation issues rather than energy lost to the outdoors.

Third party testing is conducted by professionals who have specialized equipment for blower door and duct pressure testing. See Resources for information on finding energy specialists who can conduct testing.

Resources:

- Third party plan review by a certified Home Energy Rating System (HERS) rater. A directory of HERS raters can be found on the ENERGY STAR Website at http://www.energystar.gov.
- Building Performance Institute (http://www.bpi.org) certifies whole-house building performance contractors.
- Manufacturers of testing equipment offer databases of contractors trained on proprietary equipment (e.g., The Energy Conservatory)

Envelope Leakage – Blower Door Testing

- Local utility
- Yellow pages for "energy," "energy efficiency," or "weatherization"

3.3.7 Innovative options

A. Install drain water heat recovery system.

Intent:

To reduce energy required for heating domestic hot water

Information / How to Implement:

Drain water heat recovery (DHR) systems recover some of the energy from hot water going down the drain. Drainwater heat recovery systems are available from several manufacturers and can be purchased online. One type of DHR system, the GFX, consists of flexible copper piping coiled around a copper drainpipe that is fitted into the DWV line with rubber couplings. In a typical GFX configuration, cold water running through the outer flexible copper tubing is preheated by hot water running down the drain from the main shower. The preheated water is then supplied to both the hot water tank and the cold side of the main shower—which reduces the volume and flow of hot water needed. A similar configuration can be designed for the whole house but must be more carefully designed.

Resources:

- Department of Energy - http://www.eere.energy.gov/consumerinfo/energy_savers/virtualhome/508/shower.html

- *Drainwater Heat Recovery*, NAHB Research Center technology fact sheet, http://www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2134&CategoryID=947

B. Install a desuperheater in conjunction with ground source heat pump.

Intent:

Increase the efficiency of a ground source heat pump operating in cooling mode while providing "free" hot water for domestic use. Also provide hot water while heat pump is in heating mode at high efficiency.

Information / How to Implement:

A desuperheater recovers heat that is rejected from a ground source heat pump (GSHP) operating in cooling mode, thereby increasing the cooling efficiency of the heat pump and providing "free" hot water. In heating mode, hot water is produced by the GSHP and, therefore, is produced at a high efficiency. Desuperheaters should be installed by an experience installer or come pre-installed from the factory.

Desuperheaters can be an addition to any split system A/C unit but are most commonly found on ground source heat pump units.

Resources:

- http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/BuilderGuide3E.pdf
- *Improve Energy Efficiency with Desuperheaters,* U.S. EPA fact sheet, http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/BuilderGuide3E.pdf
- Geothermal Heat Pump Manufacturer Websites

C. Install heat pump water heater. Must be rated according to the current U.S. DOE test standard and shall have an Energy Factor > 1.7.

Intent:

Reduce the energy needs for electric water heating.

Information / How to Implement:

Heat pump water heaters (HPWH) operate in a similar way to space conditioning heat pumps – they use the energy in the surrounding air to preheat water. HPWH technology has been under development for many years and is now reaching the marketplace with a number of manufacturers offering products. HPWHs operate best in hot climates where the resultant cooling of the air around the heat pump can provide additional energy savings during most of the year. HPWHs can as much as double the efficiency of electric water heating, not including any additional energy savings from space conditioning.

Careful design of the heat pump water heater system is necessary to ensure that the performance in all seasons is adequate.

Resources:

- http://www.toolbase.org/tertiaryT.asp?DocumentID=2100&CategoryID=946

- *Heat Pump Water Heaters*, Federal Technology Alert, List of heat pump water heater manufacturers at ACEEE's Website: http://www.aceee.org/consumerguide/topwater.htm

D. Install occupancy sensors for lighting control. (Points per sensor.)

Intent:

Reduce the electricity consumption associated with lighting in unoccupied rooms.

Information / How to Implement:

Purchase lighting controls from a supplier of energy efficient products or your local lighting supply store.

Resources:

- Retail outlet of energy efficient products, e.g., http://www.EFI.org, http://www.positive-energy.com, http://www.sheltersupply.com

UNDERSTANDING HVAC SYSTEM DESIGN ISSUES[6]

When designing a comfort system, it is not adequate to merely produce a heat loss and heat gain estimate. Much more is involved in the proper design and installation of a comfort system. Heat loss and heat gain estimates are part of a design procedure that flows from system selection decisions, the actual load calculations, to equipment selection procedures, to placement and selection of air distribution hardware, to duct routing and airway sizing.

Documents such as ACCA *Manual RS* provide valuable information about zoning, system concepts, equipment capability and design procedures. It is strongly recommended that system designers be familiar with the material in Manual RS.

Manual J or equivalent load calculations affect every aspect of the system design procedure. The calculations must be as accurate as possible.

- Equipment capacity that matches the size of the applied heating and cooling loads will deliver comfort, efficiency and reliability over the entire range of operating conditions.
- Heating and cooling loads determine the total air delivery requirement (blower CFM) and the air flow requirement for each room (room CFM). This airflow information is then used to select supply air outlets and to size the duct runs.
- Load information also is used to estimate purchased energy requirements and to estimate annual operating cost. In this regard, the energy and operating cost estimates will only be as accurate as the load estimate.
- The design concept must be suitable for the application:
  - Contemporary architecture tends to produce dwellings that require a zoned system and/or variable capacity equipment.
  - Custom homes that feature a large amount of architectural glass that provides a panoramic view or architectural theme may not have internal shade, or the shading device may be

[6] Information provided by the Air Conditioning Contractors of America (ACCA).

completely open when the room is occupied. In such cases, the performance of the glass (U-value and solar heat gain coefficient) has a significant effect on comfort, equipment size and energy use. If there is a large amount of South glass, cooling may be required during cold weather. These dwellings must be carefully zoned and may require year-around cooling.

- People may be uncomfortable when bathed by sunlight pouring through a window. During cold nights or cold overcast days, radiation from the occupant's skin to cold glass surfaces may cause discomfort

- External overhangs or some type of internal shading device are desirable because they provide comfort for the occupants (overhangs provide shade without interfering with the view).

***Manual S* (or equivalent) and Manufacturer's Data to Select Equipment**
In general, the effective capacity of heating and cooling equipment shall, as closely as possible, match the load when the equipment is subjected to design conditions. For instance, *Manual S* explains how to use *Manual J* output and manufacturer performance data to obtain this result. *Manual S* also provides guidelines pertaining to the acceptable amount of excess capacity and manipulating heat pump balance points.

***ACCA Manual T* (or equivalent) and Manufacturer's Data to Select Supply Outlets and Return Grilles**
Supply outlets (grilles and registers) shall be the appropriate style and size for the application and shall be in an appropriate location for the application.

- Supply outlets shall not produce objectionable noise. Design guides and manufacturers' information establish limits for face velocity.
- Supply outlets shall provide the appropriate throw for the installed location. Floor outlets shall throw the supply air to the ceiling; ceiling outlets shall throw the supply air to the wall, etc. Size depends on product performance, the supply CFM value and the face velocity limitation.
- Never blow supply air directly into the occupied zone. Occupants will complain about drafts.
- Floor outlets that blow air straight up the exposed wall are best for cold-climate heating; and if properly selected, adequate for cooling.
- Ceiling outlets are best for cooling, but will not warm slab or exposed floors during the winter.
- If high sidewall outlets are used for cooling, supply air shall not drop into the occupied zone during cooling. These devices will not warm slab or exposed floors during the winter.
- The relation between supply CFM, throw, face velocity and drop is established by manufacturer performance data. Performance is very sensitive to size and devices that appear to be generally similar can have substantially different performance characteristics.
- A low resistance return path shall be provided for every room that receives supply air - a wall opening with no door, a transfer grille or a ducted return. Door undercuts are not acceptable).
- Return grilles shall be the correct size for the grille flow rate. Filter grilles have a lower face velocity than plain grilles.
- The location of the return grille does not affect room air patterns which are controlled by the supply outlets and will not have a significant affect on pockets of stagnate air. Low returns

do "pull" warm air down to the floor and high returns do not "pull" cool air up into the occupied zone.

Manual D **(or equivalent) to Size the Duct Runs**

The resistance (inches water gauge of static pressure) of the longest circulation path (longest supply run plus longest return run) shall be compatible with the performance of the blower that is supplied with the heating-cooling equipment. Airway sizes that are compatible with the blower performance shall be increased if airflow velocity creates a potential noise problem. All systems shall have adequate provision for balancing airflow.

- The length of the longest circulation path and the available static pressure determine the friction rate used for airway sizing.
- The length of the circulation path includes the straight runs and the equivalent length of the fittings along the path. One fitting can add from 5 feet to more than 60 feet to the length of the path.
- External static pressure is determined from the equipment manufacturer's blower performance data, preferably for medium-speed operation.
- The available static pressure equals the external static pressure minus the pressure drop through all the air-side devices in the circulation path. Refer to blower table footnotes and manufacturer pressure drop data for devices that were not in place when blower performance was laboratory-tested by the equipment manufacturer.
- Accessory or after-market filters (or any device) that produce a substantial increase in system resistance shall not be installed if the blower cannot accommodate the increased resistance by speed change. An arbitrary increase in system resistance may cause low airflow to rooms, a high temperature rise across a furnace heat exchanger, or low suction pressure at the cooling coil.
- The room heat loss and heat gain estimate (*Manual J or equivalent)* and the heating and cooling factors (Manual D or equivalent) determine the design value for room airflow.
- Airway size is determined by sectional flow rate and the design friction rate value.
- The friction chart or duct slide rule used for airway sizing shall be technically correct for the type of duct material.
- Airway velocities shall not exceed specified design limits.
- Branch (runout) ducts shall be equipped with a hand damper (for balancing).

Related Comfort Conditioning System Design Considerations:

Impacts of Incorrectly Sized Heating and Cooling Equipment

- The obvious problem with significantly undersized equipment is that it will not maintain the desired set-point temperature when a passing weather system imposes a design load on the heating and cooling equipment. However, slightly undersized cooling equipment -- by a margin of 10 percent or less -- may actually provide more comfort at a lower cost.
- Oversized equipment causes short-cycles, marginalizes part-load temperature control, creates pockets of stagnate air (unless the blower operates continuously) and degrades humidity control during the cooling season (more information on this subject is provided below). Oversized equipment also requires larger duct runs, increases installed cost, increases operating cost, increases the installed load on the utility grid and causes unnecessary stress on the machinery.

Humidity Control During the Cooling Season:

- Sensible and latent cooling loads are imposed on dwellings located in climates that have a substantial amount of moisture in the outdoor air during the cooling season (wet-coil climates). When the summer design condition occurs, properly sized equipment will operate continuously or almost continuously, both loads will be completely neutralized, and the occupants will be comfortable. But, the design condition only occurs for a few dozen hours per season.
- Reduced latent capacity at part load will cause the indoor humidity to drift above the design value, which is acceptable, providing the relative humidity stays below 60 percent. The possibility for experiencing comfort problems at part load conditions is minimized by observing the following guidelines:
  - Use outdoor design conditions recommended by design manual, providing a code or regulation does not specify a different set of conditions.
  - Use the default indoor design conditions recommended by design manual, unless a code or regulation specifies a different set of conditions.
- Some climates are too dry to produce a latent load on the indoor coil. In this case, the indoor humidity depends on the moisture content of the outdoor air, the infiltration rate and the amount of moisture generated by the occupants. If the outdoor air is very dry, these factors will combine to produce an indoor relative humidity that is less than 50 percent and it could even be lower than 40 percent. But, if the relative humidity stays above 30 percent, the indoor air condition will be in the comfort zone.

Humidity Control During the Heating Season

During the heating season, very cold weather can produce discomfort. Dry-air causes a sensation of coolness, a desire to increase the thermostat set point, problems with static electricity and dry sinuses. Adding a humidifier to the heating system moderates these problems, but if a humidifier is installed, it must not produce a visible or concealed condensation problem. (See the unabridged version of *Manual J* for more information on this subject).

Part Load Days More Important than Design Load Days

As a group, homeowners are overly concerned with extreme weather conditions that occur for a few hours per season and uninformed about the significance of the part-load conditions that occur for thousands of hours per season. This lack of understanding pressures contractors to install oversized equipment. This results in systems that are more expensive to install, less efficient, less comfortable for a majority of the season and less reliable. In addition, the oversized equipment produces an unnecessary load on the electric and gas distribution systems. The solution to this problem is consumer education. Section 10-4 of Manual RS provides more information on this subject.

SECTION 4
WATER EFFICIENCY

4.1 Indoor/outdoor water use

General Resources:

All aspects of water conservation:

www.awwa.org/waterwiser/

Water Resources of the United States:

http://water.usgs.gov/

4.1.1 Hot water delivery to remote locations aided by installation of:

A. On-demand water heater at point of use served by cold water only. (Points per unit installed)

B. Control-activated recirculation system.

Intent:

Reduce water waste by using technologies that provide hot water at the tap with a minimal wait time.

Additional Information / How to Implement:

Place a water heater at the point of use or install a hot water recirculation device that is controlled by the user or an automatic device (e.g., timer or thermostat) to minimize or eliminate the waiting period for hot water at faucets. In order to save both energy and water, recirculating systems should be controlled by the user at the time of use rather than circulating hot water through the piping system continuously. Typically, in this type of controlled system, a switch or a push button located near a fixture activates a small pump that begins circulating hot water when there is demand for it.

Resources:

- Demand Hot Water Heater fact sheet: http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1318&DocumentID=3206
- Hot Water Recirculation Systems fact sheet: http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1436&DocumentID=2130
- "An Energy-Saving Product That's Actually Convenient?" Energy Design Update, July, 1997, pg. 8. This article reviews one hot water recirculation product.

4.1.2 Water heater located within 30 feet pipe run of all bathrooms and kitchen.

Intent:

Minimizing the distance between the hot water heater and major hot water uses reduces the total amount of plumbing pipe installed. This helps reduce the amount of conductive heat loss from the pipe, reduces the amount of time it takes for hot water to reach baths, the laundry area, and the kitchen (helping to conserve water), and reduces the amount of hot water left standing in pipes after a draw (which helps save energy). It has an added benefit of resource efficiency from using less piping material.

Additional Information / How to Implement:

This line item is closely related to the efficient design of the home discussed under the Resource Efficiency section. The first step in minimizing the distance between the water heater and bathrooms and kitchens is to locate those areas in close proximity to one another when designing a home. Once baths, kitchens, and laundry rooms are "clustered" or "stacked," the water heater can be located to maximize efficient delivery. The effective implementation of this line item offers material and labor savings during construction as well as water and energy savings throughout the life of the home.

Resources:

- DOE Technology Fact Sheet – Water Heating
  www.eere.energy.gov/buildings/info/documents/pdfs/26465.pdf

4.1.3 ENERGY STAR water-conserving appliances installed, e.g., dishwasher, washing machine.

Intent:

Reduce water consumption by selecting water-efficient major household appliances.

Additional Information / How to Implement:

The ENERGY STAR label identifies appliances that are at least 20% more energy efficient than other appliances of similar size and model and use less water than their standard counterparts. An ENERGY STAR washing machine uses approximately 20 gallons of water per load compared to 40 gallons for standard models. The machine also removes more water during the spin cycle, reducing drying time. ENERGY STAR washing machines are available in both top and front loading models. An ENERGY STAR dishwasher uses about 40% less water than conventional models. The ENERGY STAR label takes much of the guesswork out of selecting energy efficient appliances and equipment, making the selection process easier for builders and homeowners.

Resources:

- List of ENERGY STAR -rated appliances:
  www.energystar.gov/index.cfm?c=appliances.pr_appliances
- Vertical Axis (Top Loading) Energy-Saving Clothes Washers:
  www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1280&DocumentID=2004
- Energy Efficient Appliances, DOE Technology Factsheet:
  www.toolbase.org/Docs/MainNav/Energy/4070_doe_energyefficientappliances.pdf?TrackID=&CategoryID=1280&DocumentID=4070
- *"Dishing Out Dollars," Consumer Reports,* March, 1998, pg. 37. A comprehensive review of energy and water-efficient dishwashers.

4.1.4 Water efficient showerhead using conventional aerator or venturi technology for flow rate < 2.5 gpm

Intent:

Save water by installing low-flow showerheads.

Additional Information / How to Implement:

Low-flow showerheads conserve water by cutting the water flow through the showerhead to levels below the federal minimum standards for showerhead flow rate.

Resources:

- PATH Technology Inventory: *Low Flow Plumbing Fixtures* www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1316&DocumentID=2135
- Plumbing materials and supplies: www.plumbingworld.com

4.1.5 Water-efficient sink faucets/aerators < 2.2 gallons/minute.

Intent:

Save water by installing aerators that cut flow to levels below the federal minimum standards for faucet flow rate.

Additional Information / How to Implement:

Aerators are a water saving device. Installing aerators in faucets conserves water by restricting the water flow at the faucet outlet. Aerators can be simply screwed into most conventional faucets.

Resources:

- PATH Technology Inventory: *Low Flow Plumbing Fixtures* www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1316&DocumentID=2135

4.1.6 Ultra low flow, (< 1.6 gpm/flush) toilets installed:

A. Power-assist

B. Dual flush.

Intent:

Reduce water use associated with toilet flushing.

Additional Information / How to Implement:

Several manufacturers offer toilets that use even less water than the federally mandated 1.6 gallons per flush while still performing reliably. Power-assist toilets accomplish this with a small, electrically-powered pump and use either 1.0 or 1.4 gallons per flush depending upon liquid or solid waste. These models require a receptacle near the toilet and have a button on top that allows the user to select the desired flow. One manufacturer estimates water savings of about 2,000 gallons per year with the power-assist toilet. Other new gravity-fed models use as little as 0.8 to 1.4 gallons per flush and maintain quiet operation. Most of these models are set to a particular flow rate at installation but this setting can be adjusted later if desired.

Resources:

- ❖ EPA, *Low Flow Toilets*: www.epa.gov/owm/water-efficiency/toilets.htm
- ❖ Arizona Cooperative Extension: http://www.sahra.arizona.edu/programs/water_cons/home/bathroom_toilet.htm#3

4.1.7 Low-volume, non-spray irrigation system installed, e.g., drip irrigation, bubblers, drip emitters, soaker hose, stream-rotator spray heads.

Intent:

Minimize water use associated with outdoor water use by installing irrigation systems that offer the most effective and efficient delivery method.

Additional Information / How to Implement:

Drip irrigation systems provide water directly to root systems where it is most needed, making drip irrigation more efficient than spray systems. Water run-off and evaporation are minimized with drip irrigation systems. Drip systems are the preferred irrigation method in the desert regions of the United States, but are also recommended in any region where lawns and bedding areas require supplemental watering during the growing season.

Resources:

- ❖ *Turf and Landscape Irrigation Best Management Practices*, Irrigation Association, http://www.irrigation.org/PDF/IA_BMP_FEB_2004.pdf
- ❖ *Landscaping Irrigation Systems*, H2ouse.org., the California Urban Water Conservation Council, http://www.h2ouse.org/tour/details/element_action_contents.cfm?elementID=68BAD0B5-0C95-4AE8-8EC6EC8D76A4CBE1&actionID=BD9DA9D3-0CFA-4F05-B3CBFEC63E2EEE57&roomID=F80B1F87-C00D-498C-9C1F1E5BE9D04637

4.1.8 Irrigation system zoned separately for turf and bedding areas.

Intent:

Control irrigation to areas having different irrigation individually.

Additional Information / How to Implement:

Turf and bedding areas have different irrigation needs based on the various types of grasses and vegetation planted in those areas. Zoned irrigation systems allow for distributed control of the flow of water to each individual turf or bedding area. Zoned systems can conserve water by providing irrigation on a selective basis since most plants require 25% to 50% less water than lawns.

Resources:

- *Turf and Landscape Irrigation Best Management Practices*, Irrigation Association, http://www.irrigation.org/PDF/IA_BMP_FEB_2004.pdf
- *Landscaping Irrigation Systems*, H2ouse.org., the California Urban Water Conservation Council, http://www.h2ouse.org/tour/details/element_action_contents.cfm?elementID=68BAD0B5-0C95-4AE8-8EC6EC8D76A4CBE1&actionID=BD9DA9D3-0CFA-4F05-B3CBFEC63E2EEE57&roomID=F80B1F87-C00D-498C-9C1F1E5BE9D04637

4.1.9 Weather-based irrigation controls, e.g., moisture-sensor, computer-based weather record.

Intent:

Conserve water by providing irrigation on an "as needed" basis.

Additional Information / How to Implement:

The portion of household water used outdoors varies by climate, but can be up to 60% of all household water use. Currently, most irrigation systems are controlled by automatic timers. The systems operate at a particular time each day regardless of whether it has rained recently. Often, assessing the need for watering by visual observation or surface conditions can be difficult since watering needs are based on conditions at the roots. The recommended method for irrigation control is to use moisture sensors that activate irrigation based on soil moisture content. This not only saves water but also provides the optimum conditions for the turf grass or plants in question since over-watering can be as detrimental to healthy plant growth as insufficient water.

Computer-based controls use historical local weather data to project anticipated weather patterns and time outdoor watering accordingly.

Resources:

- *Turf and Landscape Irrigation Best Management Practices*, Irrigation Association, http://www.irrigation.org/PDF/IA_BMP_FEB_2004.pdf
- University of Nebraska drought monitoring site by U.S. state, http://drought.unl.edu/dm/monitor.html
- *Soil type and classification*, Association of American State Geologists, http://www.kgs.ukans.edu/AASG/AASG.html

4.1.10 Collect and use rainwater as permitted by local code. (Additional credit for distribution systems that use a renewable energy source or gravity.)

Intent:

Reduce water needs for irrigation by collecting and using rainwater.

Additional Information / How to Implement:

Rainwater collection systems store rain water for future watering and irrigation needs. Collecting rainwater keeps rainwater onsite, thus lowering the impact on storm water collection and conveyance systems and helping to replenish aquifers. See Resources for information about how to construct a rainwater harvesting system and related code issues. Many types of rainwater collection systems are also available commercially.

Resources:

- PATH Technology Inventory, *Rainwater Harvesting*: www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1315&DocumentID=2129
- *Harvesting Rainwater for Landscape Use*: http://ag.arizona.edu/pubs/water/az1052/harvest.html
- Garden supply houses

4.1.11 Innovative wastewater technology as permitted by local code, e.g., constructed wetland, sand filter, and aerobic system.

Intent:

Communities will often rely on municipal sewage treatment systems rather than onsite waste water systems because of the generally higher level of supervision and control involved with processing municipal sewage. However, if onsite processing is the only option for a builder on a lot, the builder will be rewarded for using advanced measures that more effectively process waste and reduce constituents such as nitrogen, which if in plentiful supply, can be harmful to water bodies.

Additional Information / How to Implement:

Innovative wastewater systems are a technological advancement over conventional septic systems. These innovative technologies treat wastewater to higher levels than what would normally be achieved by using standard septic systems, resulting in cleaner effluent discharge, improved system operation, and lower impact on the environment.

Resources:

- United States Environmental Protection Agency, Office of Water, Office of Research and Development, *Onsite Wastewater Treatment Systems Manual*, EPA/625/R-00/008, February 2002, http://www.epa.gov/ORD/NRMRL/Pubs/625R00008/html/625R00008.htm.
- University of Minnesota Extension Service: www.extension.umn.edu/distribution/naturalresources/DD7734.html

- *Alternative Individual Wastewater Systems* fact sheet: www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1325&DocumentID=2258
- *Onsite Sewage Disposal Systems* fact sheet: www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1291&DocumentID=4063

4.2 Innovative options

4.2.1 Shut-off valve or pedal-activated faucet to enable intermittent on/off operation.

Intent:

Reduce water waste by installing a faucet control that allows the user, via a (typically) hands-free method, to turn water on and off without changing the temperature.

Additional Information / How to Implement:

Motion sensor and pedal-activated faucets are water saving devices. Motion sensor devices automatically control on/off operation of the faucet. Pedal-activated faucets allow the individual to use their feet to control the faucet. Both systems conserve water by reducing the duration of a water flow event.

Resources:

- U.S. DOE, Greening Federal Facilities, Showers, Faucets and Drinking Fountains http://www.eere.energy.gov/femp/pdfs/29267-6.3.pdf

4.2.2 Separate and re-use greywater as permitted by local code.

Intent:

Reduce total household water consumption by reusing greywater, i.e., water generated from the laundry, showers, and sinks.

Additional Information / How to Implement:

Greywater reuse is the process of recycling laundry, shower, and sink water for non-potable uses. Greywater is typically used to irrigate lawns, trees, shrubs and vegetation and can also be used to flush toilets. Reusing greywater can significantly reduce total household water consumption.

Resources:

- PATH Technology Inventory: http://www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2137&CategoryID=1002
- Greywater: www.greywater.com/
- Arizona Department of Environmental Quality, *Using Gray Water at Home*: www.deq.co.pima.az.us/water/Water%20PDFs/graywater.pdf

4.2.3 Composting or waterless toilet installed as permitted by local code.

Intent:

Eliminate water use associated with toilet flushing by installing composting or waterless toilets.

Additional Information / How to Implement:

Composting or waterless toilets do not use water.

Resources

- EPA, Technology Fact Sheet, *Composting Toilets*: http://www.epa.gov/owm/mtb/comp.pdf
- Sustainable Building Sourcebook, *Composting Toilets*: http://www.greenbuilder.com/sourcebook/CompostToilet.html
- What is a composting toilet? http://www.oikos.com/library/compostingtoilet/
- Composting Toilets: http://www.compostingtoilet.org/

SECTION 5
INDOOR ENVIRONMENTAL QUALITY

General Resources

- The Sustainable Building Sourcebook, http://www.greenbuilder.com
- The Healthy House Institute, http://www.hhinst.com
- For Volatile Organic Compounds, http://www.concretenetwork.com/concrete/finished_basements/a_word_about_vocs.htm
- For Building Material Emissions Study, http://www.ciwmb.ca.gov/Publications/GreenBuilding/43303015.doc
- For spot ventilation, see the fact sheet *Spot Ventilation—source control to improve indoor air quality* http://www.toolbase.org/Docs/MainNav/Energy/3947_spotventilation1.pdf?TrackID=&CategoryID=1004&DocumentID=3947 (Sept 2004)
- EPA. *A Guide to Indoor Air Quality*, http://www.epa.gov/iaq/pubs/insidest.html (Sept 2004)
- *Mold in Residential Buildings*, http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1554&DocumentID=2944 (Sept 2004)

5.1 Minimize potential sources of pollutants.

5.1.1 For vented space heating and water heating equipment:

A. Install direct vent equipment.

Or

B. Install induced/mechanical draft combustion equipment.

Intent:

There are concerns that exhaust vents (bathroom, kitchen, etc.) can depressurize a tight home and cause by-products of combustion from appliances to be drawn into the home. If installing combustion space and water heating appliances, minimize the back drafting potential by choosing direct vent (sealed combustion) or mechanical/induced draft (power-vented) equipment. All space and water heating appliances must meet these criteria to receive points.

Note: Points can be obtained for this guideline by mixing equipment types. For instance, direct vent space heating equipment and an induced draft water heater can be installed and receive credit.

Information / How to Implement:

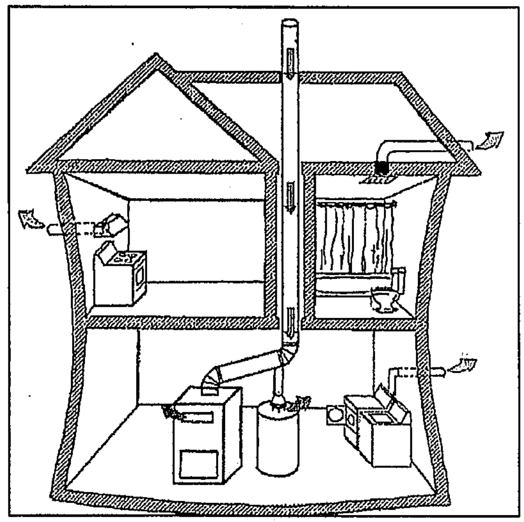
Combustion appliance manufacturers offer equipment with various means of exhausting by-products:

1) Unvented equipment (a.k.a., ventless, vent-free) where by-products are exhausted into the home;

2) Natural draft equipment (a.k.a., atmospherically vented) where environmental pressure and temperature differences cause by-products to be drawn up a chimney which is directly connected to the equipment;

3) Mechanical draft equipment (a.k.a., induced draft, power vented) where by-products are exhausted through a vent due to pressure differences created by a fan, blower, or ejector located in the vent, or

4) Direct vent equipment where all combustion takes place in a sealed chamber. Combustion air is drawn directly from the outdoors into the chamber. Products of combustion are then vented directly outdoors. Direct vent space heating equipment also has an energy benefit as compared to natural draft or mechanical draft equipment. The Annual Fuel Utilization Efficiency (AFUE) of direct vent equipment is typically above 85%.



Direct vent water heaters remain quite expensive. Mechanically vented or electric water heaters may be the most practical option for many builders wishing to comply with this guideline. Some local codes may require an outdoor source of combustion air for mechanical draft equipment.

An alternative to direct vent equipment includes isolating combustion equipment from the conditioned space such as constructing a combustion closet (see 5.1.2).

Resources:

- Koontz, M.D., N.L. Nagda. *Depressurization-Induced Backdrafting and Spillage: Implications of Results from North American Field Studies.* ASHRAE Winter Meeting; January 12–16, 2002, Atlantic City, New Jersey. AC-02-3-2. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., 2002.
- National Fire Protection Association, *American Gas Association. National Fuel Gas Code.* 2002 Edition. NFPA 54-2002. ANSI Z2223.1-2002. Section G2406 (303) Appliance Location
- American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. *ASHRAE Standard 62-1989*
- Lstiburek, J., *Builder's Guide: Hot-Dry & Mixed-Dry Climates*. Westford, MA: Building Science Corporation, September 2000.
- Lstiburek, J., *Builder's Guide: Hot-Humid Climates*. Westford, MA: Building Science Corporation, January 2002.

- Lstiburek, J., *Builder's Guide: Hot-Humid Climates*. Westford, MA: Building Science Corporation, February 2002.
- http://www.epa.gov/iaq/homes/ Search for: "Preventing Problems with Combustion Equipment" and "What You Should Know About Combustion Appliances and Indoor Air Pollution"

5.1.2 Install space heating and water heating equipment in an isolated mechanical room or closet with an outdoor source of combustion and ventilation air.

Intent:

Installing combustion appliances in an isolated space, such as in a combustion closet, can minimize the concern that combustion by-products could be drawn into the home.

Information / How to Implement:

A combustion closet is an area sealed off from the conditioned space. Insulate and seal all walls and the ceiling, install a solid door with weather stripping and a sufficient threshold, and extend ducts outside the building envelope to provide combustion and ventilation air.

Alternatives include installing direct vent or mechanical/induced draft equipment (see 5.1.a-b) or installing electric equipment.

Resources:

- Efficiency and Renewable Energy, U.S. Department of Energy. *Combustion Equipment Safety: Provide Safe Installation for Combustion Appliances*. Page 3, Combustion Closet Design chapter

5.1.3 Install direct vent sealed combustion gas fireplace, sealed wood fireplace, or sealed woodstove.

Or

No fireplace or woodstove installed.

Intent:

Direct vent sealed combustion gas fireplaces, or sealed wood burning fireplaces, and sealed woodstoves minimize the risk of smoke and combustion by-products backdrafting into the home. Outdoor air is also supplied directly to the combustion chamber so that indoor air is not required for combustion.

Information / How to Implement:

Fireplaces typically come in:

- Wood burning (uses room air for combustion, and exhausts up a chimney)
- Vented gas (uses room air for combustion, exhausts through vent or chimney),
- Direct vent gas (a.k.a., "sealed combustion," outdoor combustion air provided directly to sealed combustion chamber,, exhausts through vent or chimney), or
- Vent free gas (uses room air for combustion, and exhausts to room).

When installing a wood burning stove or fireplace, make sure it is sealed with a gasketed door. Recognize that a wood-burning fireplace is only about 10 to 30 efficient. Consider specifying an EPA-certified wood stove which have efficiencies of around 69 to 78 percent. EPA-certified woodstoves and gas appliances minimize outdoor air pollution.

Direct vent fireplaces (a.k.a., sealed combustion) are more energy efficient than wood fireplaces and atmospherically-vented gas fireplaces. They use outside air for combustion and exhaust directly to the outside. Like vented gas fireplaces, they typically use a heat exchanger to circulate warm air through the room but keep combustion air separate from room air.

Resources:

- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Consumer Energy Information: EREC Reference Briefs. *Air Pollution from Wood-Burning Appliances and Fireplaces* http://www.eere.energy.gov/consumerinfo/factsheets/ja3.html.
- Hearth, Patio, and Barbecue Association (HPBA). http://hpba.org
- HPBA fact sheet on EPA-certified wood burning http://www.hpba.org/communications/FactSheets/Fact03-EPAWoodBurn3.pdf
- HPBA fact sheet *Wood Burning Fireplaces* http://www.hpba.org/communications/FactSheets/WoodBurningFireplace.pdf
- HPBA fact sheet, *Gas Fireplaces* http://www.hpba.org/communications/FactSheets/GasFireplace.pdf
- National Fireplace Institute. http://nficertified.org. Find a certified installer. NFI Certification identifies those individuals who have passed an exam based on the knowledge needed to properly plan and install hearth products and their venting systems.
- U.S. EPA Compliance Monitoring, *Woodstoves*: http://www.epa.gov/compliance/monitoring/programs/woodstoves
- For fireplace venting options, http://www.fireplacenow.com/_content_/VentingOptions.htm (Sept 2004)

5.1.4 Ensure a tightly-sealed door between the garage and living area and provide continuous air barrier between garage and living areas including air sealing penetrations, walls, ceilings, and floors.

Intent:

Walls and ceilings between a garage and the living space should be tightly sealed to prevent car exhaust and other fumes from entering the living space. Pressure differences can cause fumes to be drawn into the living space through the common walls and ceilings between the garage and the living space. Providing a continuous, sealed air barrier along this wall and sealing all penetrations will greatly reduce the potential for contaminants to enter the home from the garage.

Automated mechanical ventilation is sometimes used to exhaust air from the garage to the outdoors. Because this type of system creates negative pressure in the garage, pollutants are less likely to be drawn into the home. However, mechanical ventilation is not a substitute for air sealing since wind speed and direction affect the performance of a mechanical exhaust system. An alternative to providing a continuous air barrier is to construct a detached garage. However, this option requires more construction materials and, therefore, has a somewhat negative impact on resource efficiency.

Information / How to Implement:

A continuous air barrier, which decouples garage air from living space air, can be accomplished in many ways. Before the framed wall is enclosed, seal or caulk all penetrations, gasket or seal sills, caulk inside edges of top and bottom plate, install cavity insulation, and install an air barrier such as rigid foam or a sheet barrier (not a vapor retarder) overlapped and taped at joints and corners and attached to the bottom plate, drywall walls and ceiling, tape and spackle all seams. Gasketed drywall or the airtight drywall approach may also be used.

At a minimum, caulk the drywall to the bottom plate, tape and spackle all drywall seams, and seal all penetrations. Only sealing the plates is not enough; air can enter between the drywall and the bottom plate, move through the stud bays, and out of the corresponding gap on the inside wall.

Resources:

- Super Good Cents Builders Field Guide – Chapter 9 – Air Tightening Specialist
- Building Science Corporation: Figure 19. http://www.buildingscience.com/housesthatwork/hotdry/tucson.htm
- http://oikos.com/library/airsealing/rim_joists.html
- Wilber, M.W. and S.R. Klossner. 1997. A Study of Undiagnosed Carbon Monoxide Complaints. Healthy Buildings/IAQ '97: Global Issues and Regional Solutions, Vol. 3, Bethesda, Maryland, Sept 27-Oct, 1997.
- Bohac, D.L. and T. H. Brown. 1997. Results from IAQ Evaluations on Cold Climate Single Family Houses Undergoing Sound Insulation. Healthy Buildings/IAQ '97: Global Issues and Regional Solutions, Vol. 3, Bethesda, Maryland, Sept 27-Oct, 1997.

5.1.5 Ensure particleboard, medium density fiberboard (MDF) and hardwood plywood substrates are certified to low formaldehyde emission standards ANSI A208.1, ANSI A208.2, and ANSI/HPVA HP1, respectively. Composite wood/agrifiber panel products must either contain no added urea-formaldehyde resins or must be third party certified for low formaldehyde emissions.

Intent:

Products certified as having low formaldehyde emissions have less detrimental effect on indoor air quality than uncertified products. In June 2004, the International Agency for Research on Cancer (IARC) declared formaldehyde a known human carcinogen. The glue used to bind materials in wooden board products often contains formaldehyde. Formaldehyde can leach out of these materials over time and into the home.

Information / How to Implement:

When purchasing wood panel products, look for materials certified as having low formaldehyde emissions.

The Composite Panel Association (CPA)'s Environmentally Preferable Product (EPP) Certification Program certifies that composite panels at least meet the appropriate ANSI low-emitting formaldehyde product criteria. Particleboard should be in conformance with ANSI A208.1-1993. For particleboard flooring, look for ANSI grades "PBU," "D2," or "D3" stamped on the panel. MDF should be in conformance with ANSI A208.2-1994, and hardwood plywood with ANSI/HPVA HP-1-1994.

Resources:

- IARC *Monographs on the Evaluation of Carcinogenic Risks to Humans* - http://monographs.iarc.fr/htdocs/announcements/vol88.htm
- http://www.buildinggreen.com - GreenSpec Directory
- The Composite Panel Association (CPA) Environmentally Preferable Product (EPP) Certification Program, http://www.pbmdf.com/AboutCPA/EPP.asp
- http://www.eppbuildingproducts.org/specifications/draftspecs/RevisedCP.attachment/30/EPPD_Composite_Panels_052405.pdf This work is currently underway and may not be completed as of the printing of these guidelines.
- GreenGuard certifies products for low emissions. As of September 2004, only one engineered wood product was listed. http://www.Greenguard.org
- For formaldehyde-free MDF, check http://www.advancedbuildings.org/main_t_finishes_formaldehyde.htm, Sept 2004.

5.1.6 Install carpet, carpet pad, and floor covering adhesives that hold "Green Label" from Carpet and Rug Institute's indoor air quality testing program or meet equivalent thresholds verified by a third party.

Intent:

Reduce VOC emissions from carpets by installing carpets certified by a third-party testing agency as low emitting.

Information / How to Implement:

The Carpet and Rug Institute administers a testing program to identify low-emitting carpets, carpet pads, and floor covering adhesives. Look for the "Green Label" when purchasing carpets. Natural fiber carpets are also good alternative floor coverings.

Resources:

- http://www.carpet-rug.com/drill_down_2.cfm?page=8&sub=4&requesttimeout=350

- ❖ Wargocki, P., D.P.Wyon, Y.K.Balk, G.Clausen and P.O.Fanger. 1999. Perceived Air Quality, Sick Building Syndrome Symptoms and Productivity in an Office with Two Different Pollution Loads. Indoor Air 1999, vol. 9: 165-179.
- ❖ Environment Protection Agency. http://www.epa.gov/iaq/formalde.html. (Sept 2004)

5.1.7 Mask HVAC outlets during construction and vacuum ducts, boots, and grilles before turning on central heating/cooling system.

Intent:

When possible, do not operate ducted HVAC equipment during construction.

Remove dust and dirt from supply and return ducts before putting the equipment into operation to minimize airborne pollutants.

Information / How to Implement:

Tightly cover openings with materials such as cardboard and tape, especially during tasks that create significant dust such as drywall or floor sanding. It is not necessary to professionally clean ducts in order to comply with this guideline. Rather, use a shop vacuum to remove dust and debris close to the openings.

Resources:

Information will be added in Version 2.

5.1.8 Use low VOC emitting wallpaper.

Intent:

Use low VOC emitting wallpaper to reduce potentially harmful VOCs from being emitted into the indoor air.

Information / How to Implement:

Use materials certified by a third party as having low VOC emissions.

The reason this line item is in the IEQ guiding principle and the low VOC paints line item is in the "Global Impacts" guiding principle is because once the homeowner moves into a new home, the vast majority of VOCs in paints have already been released to the atmosphere and are thus not a significant impact on indoor environmental quality. However, wallpaper releases VOCs more slowly, thus there is still a relatively good amount of VOCs remaining in wallpaper after a homeowner moves into a new home.

Resources:

- ❖ http://www.greenguard.org
- ❖ *Green from Wall to Wall* by Environmental Design+Construction, http://www.edcmag.com/CDA/ArticleInformation/coverstory/BNPCoverStoryItem/0,4118,128601,00.html (Sept 2004)
- ❖ *Paints and Wall Coverings* by DOE, Energy Efficiency and Renewable Energy. http://www.eere.energy.gov/femp/pdfs/29267-7.1.6.pdf (Sept 2004)

5.2 Manage potential pollutants generated in the home.

5.2.1 Vent kitchen range exhaust to the outside.

Intent:

Remove moisture, odors, and combustion by-products.

Information / How to Implement:

Install a range hood that is vented to the outside. Because a vented hood requires another puncture in the building envelope, be sure to tightly seal around the penetration. Take caution not to over-ventilate. Large kitchen exhaust fans can increase the potential for backdrafting if there are other combustion appliances in the home. (See 5.1.1 above.) The Home Ventilating Institute recommends a range hood with a minimum rate of 40 CFM per lineal foot of range top for wall-mounted hoods and 50 CFM per lineal foot for island hoods. For cooking that generates heavier steam or smoke, HVI recommends 100 CFM per lineal foot for wall-mounted hoods and 150 CFM per lineal foot island hoods. Duct length and routing can affect flow rates; be sure to verify the flow rate is as designed.

Resources:

- Home Ventilating Institute, http://www.hvi.org
- American Society of Heating, Refrigeration and Air-Conditioning Engineers, ASHRAE Standard 62-1989
- 2003 IRC page 302, Section M1506.3 Ventilation Rate
- State of California. *Reducing Indoor Air Pollution*, http://www.arb.ca.gov/research/indoor/rediap.htm (Sept 2004)
- Doiron, Jacques, *Cleaner cooking.* http://www.canadianhomeworkshop.com/quickfix/kitchen_vent.shtml (Sept 2004)
- Miltner, Karen, *Keeping Kitchen Smells Fresh.* http://www.democratandchronicle.com/homes/buyersguide/1010G221OKH_HOODS11_Homes.shtml (Sept 2004)

5.2.2 Provide mechanical ventilation at a rate of 7.5 cfm per bedroom +7.5 cfm and controlled automatically or continuous with manual override. The ventilation equipment may be:

A. Exhaust- or supply fan(s)

B. Balanced exhaust and supply fans

C. Heat recovery ventilator

D. Energy recovery ventilator

Intent:

Provide small amount of background ventilation to ensure that indoor air is exchanged at a consistent and adequate rate.

Information / How to Implement:

It is advantageous from an indoor environmental quality perspective and for energy efficiency purposes and comfort to construct a tight building envelope. Air infiltration not only contributes to energy loss but can also cause mold problems if warmer air condenses when it reaches a cooler surface as it moves through a wall cavity. However, a very tight building shell can create the need for an intentional means of introducing fresh air into the living space. Introducing outdoor air into the home in a controlled manner has both an energy and IEQ advantage.

Exhaust or Supply Fan: Kitchen or bath exhaust fans can be part of a whole-house ventilation strategy in cold climates by controlling fans with timers or humidistats. As air is exhausted from the home, the negative pressure created pulls in outdoor air from nooks and crannies in the building envelope. The practice is not recommended in warm, humid climates because humid, outdoor air traveling through a wall cavity can create moisture problems. In these climates, supply-only ventilation is preferable. For supply-only ventilation, locate the ducts carefully since cold or hot outdoor air can create comfort issues.

Balanced Exhaust and Supply Fan: Balanced ventilation does not contribute to pressure imbalances between indoors and out. As air is exhausted by one (or more) fans, fresh air is introduced by another. One option for balanced ventilation is to use bath fans for the exhaust and to install a small duct from outside to the return side of the air handler on a central heating or cooling system. Controls and timers are then used to operate the fans and air handler simultaneously or as desired. Outdoor air can also be supplied directly to the home with a separate fan, but take care in locating the ducts so that comfort is not compromised.

Heat or Energy Recovery Ventilators: These systems are also a form of balanced ventilation. In addition to supplying fresh air and exhausting stale air, they precondition the incoming air to some degree. Heat recovery ventilators exchange sensible heat while energy recovery ventilators transfer moisture to some extent as well. Thus, in a humid climate, some moisture from the incoming air is transferred to the exhaust stream. Energy recovery ventilators are not dehumidifiers; they transfer moisture from one air stream to another. For severely humid climates, one should consider a dehumidifying ventilator. Typically, heat recovery ventilators are recommended for cold climates and energy recovery ventilators for hot climates. However, if dry indoor air is a potential issue in a heating dominated climate, an energy recovery ventilator may be preferred.

See also Section 3.3.1B under the Energy Efficiency section.

<u>Resources:</u>

- American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. ASHRAE Standard 62-1989

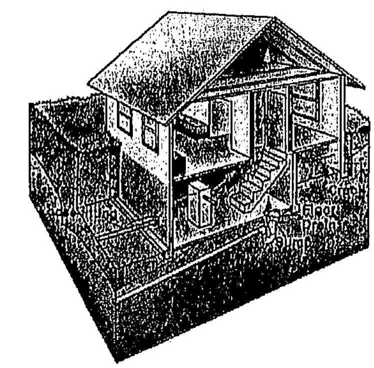
5.2.3 Install MERV 9 filters on central air or ventilation systems.

<u>Intent:</u>

To reduce the amount of airborne particulates.

<u>Information / How to Implement:</u>

MERV 9 filters remove particles larger than 3 microns and are more effective than standard spun fiber filters. MERV 9 filters would capture dust, but not contaminants such as molds and bacteria which are in the 1 micron range. Some studies have shown that 97% of airborne particles are 1 micron or less. Filters with a greater efficiency are often not recommended for space heating and cooling equipment because they may restrict air flow too much. More efficient filters such as MERV 9 also have a resource efficiency benefit from the standpoint that more dust is captured by the filter and is not deposited on the air handler.



Radon can enter a house through many paths.

Resources:

- ❖ National Institute for Occupational Safety and Health. Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks. http://www.cdc.gov/niosh/docs/2003-136/2003-136c.html (Sept 2004)
- ❖ CHMC " What a Furnace Filter Can Do For You" http://www.cmhc-schl.gc.ca/en/burema/gesein/abhose/abhose_ce22.cfm (September 2004)

5.2.4 Install humidistat to control whole-house humidification system.

Intent:

Control excessive humidification, which can result in moisture damage.

Information / How to Implement:

Indoor humidity should be between 30 and 60 percent. Indoor humidity below 30 percent causes dry eyes, nose, and throat which is not only uncomfortable, but also an invitation for bacteria and viruses.. At the other extreme, indoor humidity above about 60% percent can contribute to the potential for mold growth. Given temperatures between 40and 80 degrees Fahrenheit and a food source (wood, paint, dirt, dust), mold will grow within 24-48 hours. Therefore, if a whole-house humidification system is installed, it should have an adjustable humidistat control to avoid excessive humidification.

Resources:

- ❖ ToolBase Website. Humidity-Sensing Control Device http://www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2096&CategoryID=960 (Sept 2004)

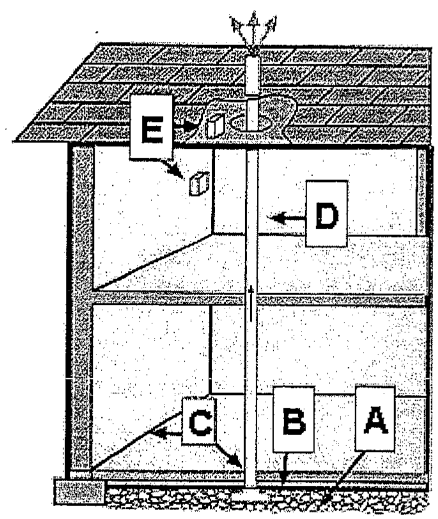
5.2.5 Install sub-slab de-pressurization system or infrastructure to facilitate future installation of radon mitigation system. **When applicable, the more stringent requirement of local building code and this provision shall apply.*

Intent:

Prevent radon gas from entering the home.

Information / How to Implement:

Radon is a naturally occurring gas spontaneously produced from the decay of radium. Radon levels can vary between outdoor air, indoor air, soil, and ground water. Radon is a carcinogen that can enter through voids in a homes foundation and become trapped inside. Radon gas can easily be directed outside of the home with a few basic construction designs.

Text and graphic in table from: http://www.ep	Radon from USGS2.bmp
A. Gas Permeable Layer This layer is placed beneath the slab or flooring system to allow the soil gas to move freely underneath the house. In many cases, the material used is a 4-inch layer of clean gravel.	
B. Plastic Sheeting Plastic sheeting is placed on top of the gas permeable layer and under the slab to help prevent the soil gas from entering the home. In crawlspaces, the sheeting is placed over the crawlspace floor.	
C. Sealing and Caulking All openings in the concrete foundation floor are sealed to reduce soil gas entry into the home.	
D. Vent Pipe A 3- or 4-inch gas-tight or PVC pipe (commonly used for plumbing) runs from the gas permeable layer through the house to the roof to safely vent radon and other soil gases above the house.	
E. Junction Box An electrical junction box is installed in case an electric venting fan is needed later.	

Note that in areas designated as high radon areas, special considerations should be taken to treat well water. Simple water treatments are available. For more information, call EPA's Drinking Water Hotline at (800) 426-4791 or visit www.epa.gov/safewater/radon.html If your water comes from a private well, you can also contact your state radon office.

Resources:

- 2003 IRC page 559
- HBA: Use radioactivity maps from USGS, state geological surveys, colleges/universities to better know the dangerous radon zones in your area. http://energy.cr.usgs.gov/radon/georadon/4.html
- Radon map for Prince George's and Montgomery counties from USGS http://energy.cr.usgs.gov/radon/georadon/4.html

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- EPA's map of radon zones by county http://www.epa.gov/radon/zonemap.html
- HBA: EPA also recommends contacting your state radon representative. EPA has a list of contacts on their Website at: http://www.epa.gov/iaq/whereyoulive.html
- http://www.epa.gov/radon/
- *Radon Resistant New Construction* - http://www.epa.gov/radon/construc.html
- 2000 IRC, page 564, *Radon-resistant construction details for four foundation types.*
- For Radon remediation, check http://www.toolbase.org/secondaryT.asp?TrackID=&CategoryID=1174

5.2.6 Verify all exhaust flows meet design specifications.

Intent:

To ensure all exhaust flows are operating as designed.

Information / How to Implement:

If ductwork is not properly sized and installed, fan flow may be restricted and fans may not exhaust air at their rated capacity. For example, a fan rated at 50 CFM may only exhaust 35 CFM if duct runs are extremely long or if ductwork is kinked during installation. Without adequate fan capacity, moisture may not be adequately removed. Properly size ducts in accordance with the manufacturer's recommendation for duct diameter and maximum duct length. Fans should perform within 10% of their rated capacity. After installation, visually inspect the duct length, look for crimped or damaged ducts, check for missing parts, and ensure that connections are secure. A more accurate method of checking fan air flow is to use a flow hood or pitot tube and manometer. Ask the installer about methods of checking air flow.

Resources:

- ACCA Manual D http://www.cmhc-schl.gc.ca/en/burema/gesein/abhose/abhose_ce17.cfm
- Flow hood equipment - http://www.energyconservatory.com/products/products1.htm

5.3 Moisture management (vapor, rainwater, plumbing, HVAC)

Intent:

Reduce risk of moisture accumulation which can lead to deterioration of building products and potential mold problems.

Information / How to Implement:

See Resources section.

Resources:

- Lstiburek J., and J. Carmody, *Moisture Control Handbook, Principles and Practices for Residential and Small Commercial Buildings*, Wiley, 1996.

5.3.1 Control bathroom exhaust fan with a timer or humidistat.

Intent:

To ensure that fans are operated in a manner that removes moisture without relying on input from the homeowner. Also, remove residual moisture from bathrooms after the occupant has left the room.

Information / How to Implement:

Often, bath fans are used infrequently because of their noise, a lack of understanding of their importance by the homeowner, or simply because the homeowner is not in the habit of doing so. Installing controllers on fans, especially timers or humidistats that remove residual humidity after a person leaves the bathroom, is an effective method for removing interior generated moisture at its source. Timers can also prevent unnecessary fan energy use that occurs when a fan is inadvertently left on.

Timers and humidistats are basically upgraded switches. They are wired in and mounted like a typical switch. Timers can typically be set to run from 10 to 60 minutes. Homeowners should be instructed to run bathroom exhaust fans for 20 minutes after a bath or shower. Humidistats will automatically cycle the fan on and off to maintain proper humidity levels; they can be adjusted to operate between 20% and 80% relative humidity. Timers and humidistats cost about $25 and up. Bath fans are also available with integral humidistats and timers.

See Section 3.3.2 for information about energy efficient exhaust fans.

Resources:

- http://energyoutlet.com/res/fan/
- http://www.cmhc-schl.gc.ca/en/burema/gesein/abhose/abhose_ce17.cfm
- *Moisture Control in Bathrooms* by Home Energy Magazine Online. http://hem.dis.anl.gov/eehem/98/980310.html (Sept 2004)
- *Spot ventilation—source control to improve indoor air quality.* http://www.toolbase.org/docs/MainNav/Energy/3947_spotventilation1.pdf (Sept 2004)

5.3.2 Install moisture resistant backerboard, not paper-faced sheathing, under tiled surfaces in wet areas.

Intent:

To reduce the risk of problems if water penetrates tile surfaces in kitchens and baths.

Information / How to Implement:

A cement based backerboard does not contain organic paper that can deteriorate, swell (potentially causing cracking in the grout), and be a substrate for mold growth when wetted. Cement backerboard is resistant to the deleterious effects of moisture.

Resources:

- Backerboard manufacturer Websites for installation information (e.g., WonderBoard, Durock)
- Tile Council of America, 2003-2004 *Handbook for the Installation of Ceramic Tile,* http://www.tileusa.com.

5.3.3 Install vapor retarder directly under slab (6-mil) or on crawl space floor (8-mil). In crawl spaces, extend poly up wall and affix with glue and furring strips, or damp proof wall below grade. Joints should be lapped 12 inches.

Intent:

To prevent moisture migration from the ground through wicking action (through slab) or by vapor movement (in crawl space).

Information / How to Implement:

A vapor retarder should be continuous with joints lapped 12 inches and taped, if possible. Any penetrations or other areas where the vapor retarder has been compromised should be sealed with tape or caulk.

Resources:

- Carter, Tim. *Vapor Retarders Will Stop Odors and Moisture.* http://www.askthebuilder.com/printer_279_Vapor_Retarders_Will_Stop_Odors_and_Moisture.shtml (Sept 2004)
- Makela, Eric, et al. *How to construct unventilated crawlspace to meet the provisions.* USDOE. http://www.holtonhomes.com/webcast_04_crawlspaces.pdf (Sept 2004)
- *Crawlspace Moisture Control,* fact sheet by Dominion Power, http://www.dom.com/customer/efficiency/res/answers/pdf/crawlspaces.pdf%20
- *EEBA Builders' Guides (for Cold, Mixed-Humid, Hot-Dry/Mixed-Dry, and Hot-Humid Climates),* available from the Energy and Environmental Building Association's Website at http://www.eeba.org/mall/builder_guides.asp

5.3.4 Protect unused moisture-sensitive materials from water damage through just-in-time delivery, storing unused materials in a dry area, or tenting materials and storing them on a raised platform.

Intent:

Prevent wetting of building materials through proper storage techniques during construction. Wetting of building materials can lead to dimensional instability, deterioration, and mold growth.

Information / How to Implement:

Lumber should be inspected upon delivery for moisture and mold. Delivery should be scheduled so that lumber is used soon after it is received at the site. Lumber should not be stored in direct contact with the ground: it should be elevated to allow air circulation and to prevent absorption of ground moisture. Lumber that is stored outside should be covered in an open area in a way that will protect the wood from rain and snow but will also allow water vapor to escape, such as by covering it with housewrap (plastic sheeting can trap moisture). Interior architectural items such as flooring, trim, and cabinets should be stored indoors until they reach equilibrium with interior moisture levels. This guideline is also a cost effective measure—by protecting materials from the weather, waste due to warping, shrinking, and swelling can be avoided.

Resources:

- *Panel Selection, Handling, Storage. OSB Design and Construction Guide.* March 2000. PFS Research Foundation. Madison, WI.
- Forest Products Laboratory. 1999. *Wood handbook—Wood as an engineering material. Gen.* Tech. Rep. FPL-GTR-113. Madison, WI. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 463 p. see Section 12, page 18. Design Factors Affecting Dimensional Change.
- ToolBase. http://www.toolbase.org/docs/ToolBaseTop/Research/3464_HelpingHomebuyeresUnderstandMold.pdf (Sept 2004)
- *Proper Lumber Storage*, Southern Pine Council, http://www.southernpine.com/lumberstorage.shtml
- *Proper Storage and Handling of Glulam Beams,* APA—The Engineered Wood Association, http://www.apawood.org/pdfs/managed/R540.pdf
- *Storage and Handling of APA Trademarked Panels,* APA—The Engineered Wood Association, http://www.apawood.org/pdfs/managed/U450.pdf
- *Storage, Handling, and Safety Recommendations for APA Performance Rated I-Joists*, http://www.apawood.org/pdfs/managed/Z735.pdf
- (Just-In-Time Delivery) *Industrializing the Residential Construction Site*, 2000. Center for Housing Research, VPI. Available from the U.S. Department of Housing and Urban Development.

5.3.5 Keep plumbing supply lines out of the exterior walls.

Intent:

Reduce the potential for condensation on supply pipes by keeping pipes in conditioned space (where pipes are not exposed to large temperature and humidity differentials). Also reduces the consequences of a potential plumbing leak—which could lead to wetting of structural members, insulation, and interior finishes.

Information / How to Implement:

Try to cluster bathrooms and other hot water uses, e.g., “stacked” bathrooms, to minimize the need for running supply lines on exterior walls. Water supply lines can be run through duct chases (designed for keeping ducts in conditioned space). When piping must be located in exterior walls, insulation should be placed between the exterior sheathing and the pipe, but not between the pipe and the interior wall (to prevent freezing).

Resources:

- *Builder's Guide to Placement of Ducts and HVAC Equipment in Conditioned Space*, 2000, NAHB Research Center. Available at http://www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2570&CategoryID=110

- Lewis, Bill. *Preventing Frozen Water Pipes.* http://homerepair.about.com/cs/plumbing/a/frozen_pipes_b3.htm (Sept 2004)

5.3.6 Insulate cold water pipes in unconditioned spaces with ½" insulation or other coating that comparably prevents condensation.

Intent:

Reduce the potential for condensation on cold water supply pipes located in unconditioned space by insulating the pipes. This guideline has more relevance in hot, humid climates where piping is more likely to be located in an unconditioned area. Cold water piping installed in crawl spaces can pose a condensation problem in colder regions during the summer months.

Information / How to Implement:

Foam insulation for insulating pipes is readily available and easy to install.

Resources:

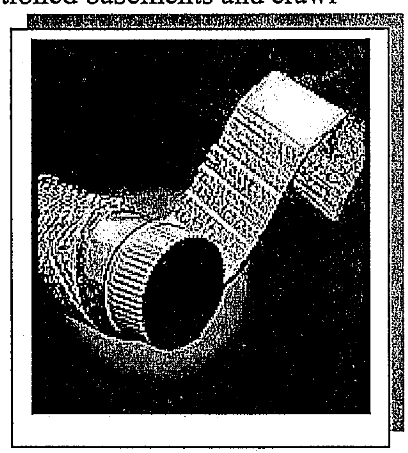
- *Preventing and Thawing Frozen Pipes.* http://www.prepare.org/basic/frozen.htm (Sept 2004)
- Do It Yourself. http://www.diynet.com/diy/diy_kits/article/0,2019,DIY_13787_2275412,00.html (Sept 2004)

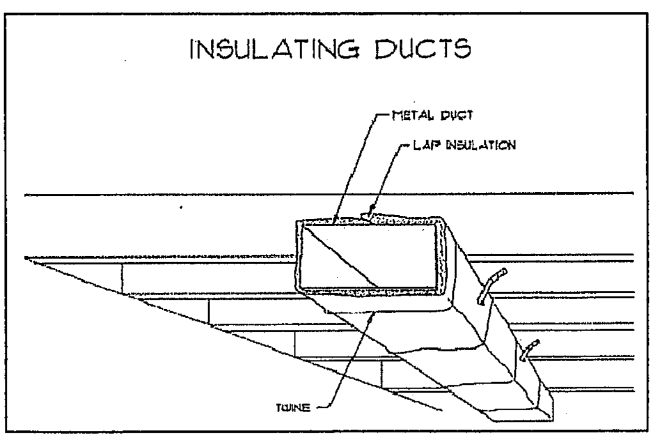
5.3.7 Insulate HVAC ducts, plenums, and trunks in unconditioned basements and crawl spaces to avoid condensation.

Intent:

To prevent condensation on the outside of cold HVAC ducts located in unconditioned basements and crawlspaces that can lead to moisture problems in those areas.

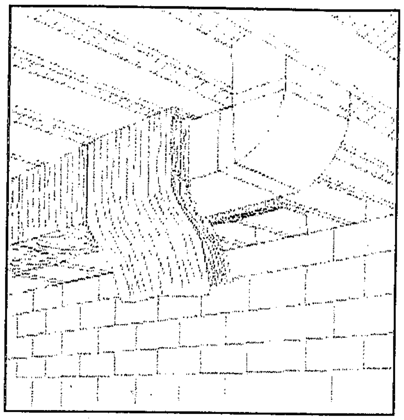
Information / How to Implement:





(photo from energyoutlet.com, http://energyoutlet.com/res/ducts/insulating-480.gif)

A008724



(Source: Reflectix)

http://www.mme.state.va.us/de/energybook/hbchap5.html

After sealing ductwork, use spray foam or wrap a flexible insulation product (e.g., reflective insulation, fiberglass batts) around metal supply ducts, plenums and trunks in basements and crawlspaces. Do not use flexible ductwork in crawlspaces, as it can be an entry point into the home for vermin.

Resources:

- Energy Outlet information on duct sealing, available at http://www.energyoutlet.com/res/ducts/insulating.html
- *Crawlspace Condensation* by Home Energy Magazine Online http://hem.dis.anl.gov/eehem/01/010304.html (Sept 2004)
- *Insulating Ducts for Efficiency.* http://www.bobvila.com/ArticleLibrary/Subject/HVAC/Insulation/InsulatingDucts.html (Sept 2004)

5.3.8 Check moisture content of wood before enclosing on both sides. Ensure moisture content of subfloor/substrate meets the appropriate industry standard for the finish flooring material to be installed.

Intent:

Because wood's ability to dry is compromised when it is not subject to free airflow, moisture content should be acceptable before the wood is enclosed in a wall or floor joist cavity. Reduce the risk of shrinkage and mold on lumber by ensuring the moisture content of dimensional lumber is below 19% before enclosure.

Information / How to Implement:

Use a moisture meter (preferably a probe-type meter which is more accurate than the scanning type) to measure the moisture content in the wood and wood subfloor. A sample of wood materials can be checked relatively quickly before installing finish materials.

For hardwood flooring over a truss or joist system, the average moisture content of framing members and subflooring should be below 12%-14% before delivery of the flooring.

When installing flooring over a concrete slab, testing a concrete slab requires use of a calcium chloride test; the test should show a moisture content of 3 pounds or less (if no moisture retarder is installed) and 4-7 pounds (if a moisture retarder is installed). Per the National Wood Flooring Association's guidelines, wood flooring should not be installed over concrete with readings exceeding 7 pounds calcium chloride. Use a surface moisture meter and perform a calcium chloride test to measure moisture in a concrete slab/subfloor.

Resources:

- National Wood Flooring Association, *Hardwood Flooring Installation Guidelines*, http://www.nwfa.org.
- The Wood Flooring Manufacturer's Association, *Installing Hardwood Flooring,* http://www.nofma.org/installation1.htm
- *Electric Moisture Meters*, ToolBase Services fact sheet, available at http://www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2120&CategoryID=1013Golden, J.A., 1998, *Moisture Testing Guide for Wood Frame Construction Clad with Exterior Insulation and Finish Systems,* p. 7-8. Available at http://www.toolbase.org/docs/MainNav/MoistureandLeaks/876_protocol5A.pdf
- *Computing Moisture Content of Wood.* http://www.woodbin.com/ref/wood/emc.htm (Sept 2004)
- EPA Moisture Content Calculation. http://www.epa.gov/athens/learn2model/part-two/onsite/mc.htm (Sept 2004)

5.4 Innovative options

Information will be added in Version 2.

SECTION 6
OPERATION, MAINTENANCE, AND HOMEOWNER EDUCATION

Ensure that homeowners are aware of the green features of their new home, know how to operate and maintain the home to achieve the highest level of environmental performance, and have a resource for warranty issues.

6.1 Provide Home Manual to owners/occupants on the use and care of the home that includes all of the items below.

A. Narrative detailing the importance of maintenance and operation to keep a green built home green.

B. Local Green Building Program's certificate.

C. Warranty, operation, and maintenance instructions for equipment and appliances.

D. Household recycling opportunities.

E. Information on how to enroll in a program for purchasing energy from a renewable energy provider.

F. Explain the benefits of using compact fluorescent light bulbs in high usage areas.

G. Provide a list of habits/actions to optimize water and energy use.

H. Local transportation options.

I. Clearly label safety valves and controls for major house systems.

Intent:

Help home owners to "live green" in their green built home.

Information / How to Implement:

Gather information for homeowners from local and national resources (see Resources). Include information about the green features of the home as well as tips for living in the home with less impact on the environment. Ask your local Green Building program if they offer a sample Green Homeowners' Manual.

Resources:

- Fannie Mae's, *Home Performance Power: Fannie Mae's Guide to Buying and Maintaining a Green Home.* For a copy, call Fannie Mae's Consumer Resource Center at 1-800-7FANNIE (1-800-732-6643).
- NAHB's *Your New Home and How To Take Care of It.*
- *The National Home Maintenance Manual,* by California Building Standards.
- Your local HBA's Green Building Program office. List of local Green Building Programs at http://www.toolbase.org (click on "Green Building")
- Various manufacturers
- City, county, or township recycling information
- U.S. DOE's Green Power Network: http://www.eere.energy.gov/greenpower/

- Lighting energy savings calculator at http://www.goodmart.com/light_bulb_energy_saving_calculator.aspx
- Water saving tips at http://www.h2ouse.org/. Energy Saving tips: http://www.eere.energy.gov/consumerinfo/energy_savers/ and http://www.aceee.org/consumerguide/chklst.htm
- Metropolitan area, city, county, township, or private public transit information (usually listed in the front matter of the phone book)
- *Homeowner's Manual—At last, an owner's manual for your new home*. By CMHC. http://www.cmhc-schl.gc.ca/en/bureho/buho/buho_002.cfm (Sept 2004)
- National Environmental Services Center, http://www.nesc.wvu.edu/nsfc/NewReleases/nsfc_NR_11_14_03.htm (Sept 2004)
- Community Associations Institute, http://www.caionline.org/about/homeowner_education.cfm (Sept 2004)
- Massachusetts Housing Partnership, http://www.mhp.net/homeownership/education.php (Sept 2004)
- How-To Publications by Family Resource Management, College of Agriculture & Home Economics. http://www.cahe.nmsu.edu/pubs/_g/ (Sept 2004)
- Papolos, Janice. *The Virgin Homeowner: The Essential Guide to Owning, Maintaining, and Surviving Your Home*, Penguin Books. ISBN: 0140274766.
- For earthquake safety. http://www.seismic.ca.gov/pub/CSSC_2002-04_HOG.pdf (Sept 2004)
- For fire prevention http://www.ofm.gov.on.ca/english/FirePrevention/FireSmart%20Communities/pdf/User%20guide.pdf (Sept 2004)
- For soil-lead hazard. http://www.epa.gov/region01/leadsafe/pdf/chapter8.pdf (Sept 2004)
- For septic system by University of Minnesota Extension Service. http://www.extension.umn.edu/distribution/naturalresources/DD6651.html (Sept 2004)
- For pest control and pesticide safety, http://pep.wsu.edu/psp/scripts/documents.asp?qryType=new, and http://scholar.lib.vt.edu/ejournals/JPSE/v5/v5hipkinsra2.pdf (Sept 2004)
- For HVAC. http://www.healthgoods.com/Education/Healthy_Home_Information/Space_Heating_and_Cooling/sizing_heat_and_ac.htm (Sept 2004)

6.2 Optional items to include in the Home Manual (choose at least 5)

A. Provide a list of local service providers that focus on regularly scheduled maintenance and proper operation of equipment and the structure (sealants, caulks, gutter and down spout system; shower/tub surrounds, irrigation systems, etc.).

B. Supply homeowner with a photo record of framing showing utilities installed. Photos should be taken prior to installing insulation, clearly marked, and provided in homeowner's manual.

C. Give owner/occupants list of the Green Building Guideline items that are included in the home.

D. User-friendly maintenance checklist.

E. Proper handling and disposal of hazardous materials.

F. Information on organic pest control, fertilizers, de-icers, and environmental cleaning products.

G. Native or low-water landscape.

H. Information on how to keep a home's relative humidity in the range of 30-60%.

I. Information about checking crawlspace for termite tubes periodically.

J. Instructions for keeping gutters clean. Information should note that downspouts should divert water at least five feet away from foundation.

Intent:

Provide further information about maintenance and operation of a green home and the surrounding site.

<u>Information / How to Implement:</u>

Provide above information in the homeowner's manual

<u>Resources:</u>

- Home*a*Syst, *An Environmental Risk-Assessment Guide for the Home, Healthy Home Tool*, available at http://www.uwex.edu/homeasyst/
- Local Green Building Checklist, or other documents
- EPA document: http://www.epa.gov/epaoswer/non-hw/househld/hhw.htm
- Check with the local or state environmental or solid waste agency to see if there is a hazardous waste drop-off day. Local recycling information may cover hazardous wastes. County or state may have Cooperative Extension fact sheets geared toward your municipality (see, for example, http://www.epa.gov/grtlakes/seahome/housewaste/src/open.htm)
- Local Cooperative Extension office should have printed information. Also, organic-based lawn services, such as NaturaLawn, usually have printed information.
- County or state Cooperative Extension publications
- Cooperative Extension publications for information about termite tubes, where to look for them, and what they look like. See, for example, http://www.uky.edu/Agriculture/Entomology/entfacts/struct/ef604.htm

6.3 Provide education to owners/occupants in the use and care of their dwellings.

A. Instruct homeowner/occupants about the building's goals and.strategies and occupant impacts on costs of operating the building. Provide training to owners/occupants for all control systems in the house.

Intent:

During the walk through, demonstrate how to control of all the mechanical systems in the home. Demonstrate how to use all controls such as thermostats, lighting controls and fan controls.

Information / How to Implement:

Resources:

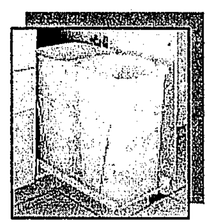
- National Association of Home Builders, *Your New Home and How to Take Care of* It. Washington, DC: BuilderBooks, 2001, 60 pages.
- Provide homeowners these pages and pages of tips on maintenance to help keep their new home performing at its peak. In the back there are pages on which to note maintenance dates and remarks.
- http://www.builderbooks.com
- 800-223-2665
- Manuals from manufacturers for reference.

6.4 Solid Waste

A. Encourage homeowners/occupants to recycle by providing built-in space in the home's design for recycling containers.

Intent:

Make it convenient for homeowners to recycle. (Photo from http://www.toolbase.org, courtesy of Rev-a-Shelf)



Information / How to Implement:

Include a recycling center in or near the kitchen either under the sink, in an island near the sink, or in a pantry. Credit is given in this line item for an in-counter compost bin, also.

Hardware is available for recycling bins to rest on slides. Most under sink recycling systems can fit two bins under one side of the sink: allowing plenty of room for other typical under-sink items.

Resources:

- http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1280&DocumentID=2001

6.5 Innovative options

Information will be added in Version 2.

SECTION 7
GLOBAL IMPACT

7.1 Products

7.1.1 Manufacturer' operations and business practices include environmental management system concepts (the product line, plant, or company must be ISO 14001 certified)

Intent:

Use products that come from organizations that have taken the time and resources to create an environmental management system (EMS) that conforms to the ISO 14001 standard.

Information / How to Implement:

See Resources section.

Resources:

U.S. EPA Position Statement on Environmental Management Systems (EMS), http://www.mswg.org/USEPAPS/EMSposState.pdf

7.1.2 Choose low- or no-VOC indoor paints. VOC concentrations (grams/liter) of interior paints should be equal to or less than those specified by the EPA's Environmentally Preferable Purchasing Program as follows:

A. Interior latex coatings: Flat: 100 grams/liter

B. Non-flat: 150 grams/liter

C. Interior oil-based paints: 380 grams/liter

Intent:

Reduce the amount of volatile organic compounds (VOCs) released to the outdoors and thus reduce the potential formation of ground-level ozone.

Additional Information / How to Implement:

VOC content of paints is categorized under Global Impacts rather than Indoor Environmental Quality because, once a homeowner moves into a new home, the vast majority of VOCs in paints have been released to the atmosphere and are thus not a significant impact on indoor environmental quality.

Although emissions of VOCs from paints can negatively affect indoor air, the half-life of VOCs in paints is usually shorter than the time between painting and homeowner occupancy. For example, paints cure and finish off-gassing in approximately four days; a homebuyer typically occupies a home two to four weeks after painting.

Although the builder's paint isn't a big indoor pollutant, homeowners can be informed about the use of low-VOC emitting paints when re-painting the home in the future. There are paints certified as low-VOC emitting which are certified through GREENGUARD—an independent air quality certification organization.

Note that low-VOC content paints are not the same as low-VOC emitting paints. The U.S. EPA established low-VOC content standards based on a set of ozone-forming chemicals; these standards do not take into account the many other potentially hazardous chemicals found in indoor paint.

Low-VOC content paints are widely available; by choosing them you contribute to a healthier environment. Check the label on the paint can for the VOC content.

Resources:

- Green Seal certifies low content paints: http://www.greenseal.org/certproducts.htm#paints
- The GREENGUARD Environmental Institute (GEI) provides a guide to third-party certified low emitting interior products and building materials, http://www.greenguard.org/
- Master Painters Institute, http://www.paintinfo.com
- National Paints and Coatings Association (NPCA), http://www.paint.org
- EPA's Environmentally Preferable Purchasing Guide. http://www.epa.gov/oppt/epp/documents/pfs.htm (Sept 2004)

7.1.3 Use low VOC sealants. VOC concentrations for construction adhesives and sealants should meet the limits specified in the California Air Resources Board *Regulation for Reducing Volatile Organic Compound Emissions from Consumer Products* as outlined below.

A. Construction adhesives: the greater of 15% by weight or 200 grams/liter

B. Sealants and caulks: the greater of 4% by weight or 60 grams/liter

C. Contact adhesives: the greater of 80% by weight or 650 grams/liter

Intent:

Use low VOC sealants to reduce potentially harmful VOCs from being emitted into the environment.

Information / How to Implement:

Note that, like low-VOC content paints, low-VOC content sealants is not the same as low-VOC emissions. The California Air and Resources Board created low-VOC content standards based on a set of ozone causing chemicals. Also, VOC content does not directly equate to VOC emissions. In addition, VOC emission rates and times are greatly affected by temperature, humidity, age, and other factors.

Resources:

- http://www.arb.ca.gov/consprod/consprod.htm
- California Air Resources Board, http://www.arb.ca.gov/consprod/regs/Cpreg.doc (Sept 2004)

7.2 Innovative options

7.2.1 Builder's operations and business practices include environmental management system concepts (the builder must be ISO 14001 certified)

Intent:

Institutionalize and consistently apply the concept of incorporating environmental considerations into all phases of the company's operations.

Additional Information / How to Implement:

At the time this document was created, there was only one builder in the U.S. that was ISO 14001 certified: Skanska USA.

You may be familiar with the 9000 series of international standards regarding quality management systems (QMS). As a continuation of this management systems standardization process, the ISO 14000 series of international standards have been developed for environmental management systems (EMS).

In September 1996, the International Organization for Standardization (ISO) finalized the ISO 14001 standard for environmental management systems (a revision is anticipated to be issued in 2004).

Similar to the QMS implemented for ISO 9001, the ISO14001 requires implementation of an EMS in accordance with defined, internationally recognized standards (as set forth in the ISO14001 specification). The ISO14001 standard specifies requirements for establishing an environmental policy, determining environmental aspects and impacts of products/activities/services, planning environmental objectives and measurable targets, implementation and operation of programs to meet objectives and targets, checking and corrective action, and management review.

ISO14001 standards require a company to document and make available to the public an Environmental Policy. In addition, the company must review the environmental aspects and impacts of products and then create and implement procedures to reduce the environmental impacts. Based on these environmental aspects and impacts, environmental goals and objectives must be established that are consistent with the environmental policy. The process of creating an EMS can help a company better understand how it impacts the environment through all of its business processes.

Resources:

- Skanska USA's EMS information can be found at their Website under Management Systems, http://www.skanska.com/
- The ISO 14001 Information Center provides free information on the EMS, http://www.iso14000.com/

APPENDIX A
SITE PLANNING AND LAND DEVELOPMENT

1.0 Identify goals with your team.

Establish a knowledgeable team and communicate in writing.

Intent:

One of the earliest challenges for a builder in developing a "green" lot is assembling an effective team to help implement best "green" practices throughout the process. Those involved in the development phase must understand the mission of the site, what it means to be a "green" lot, and why "green" practices should be followed. Once this baseline is established, coordination and communication with and among the various team members is essential to successfully develop a "green" lot.

Additional Information / How to Implement:

Before ground is broken, all parties that will be involved in lot development (the team) should understand that the lot will be developed as a "green" site. Possible team members can include staff, site superintendents, utilities, excavators, landscape architects, wildlife biologists, ecologists, and arborists. Once the "green" intent of the builder is communicated to the lot development team, the builder should work with the team throughout the development process to identify and delegate responsibilities of team members, as well as facilitate coordination between the members to achieve best green practices.

Resources:

- American Society of Consulting Arborists, http://www.asca-consultants.org/why.html.
- American Society of Landscape Architects, http://www.asla.org/members/pigroups.cfm.
- International Society of Arboriculture, http://www.isa-arbor.com/home.asp.
- Society of American Foresters, http://www.safnet.org/certifiedforester/.
- The Ecological Society of America, http://www.esa.org/.

Establish a "green development" mission statement.

Intent:

To communicate the relevant, streamlined goals into the field to ensure that they are put into practice.

Additional Information / How to Implement:

Post the mission statement for all project personnel to see.

Resources:

Information will be added in Version 2.

Identify goals and objectives.

Intent:

Those involved in the development phase must understand the site's goals and objectives, what it means to be a "green" development, and why they should follow "green" practices.

Additional Information / How to Implement:

Information will be added in Version 2.

Resources:

Information will be added in Version 2.

Identify team member roles and how they relate to various phases of development.

Intent:

Before ground is broken, all parties involved in lot development (the team) should understand that the lot will be developed as a "green" site.

Additional Information / How to Implement:

Examples of possible team members include staff, site superintendents, utilities, excavators, landscape architects, wildlife biologists, ecologists, and arborists.

Resources:

Information will be added in Version 2.

Provide training to onsite supervisors and team members on the green development practices that will be instituted onsite.

Intent:

The noblest intentions pursued in designing a site are practically achieved through onsite supervision during the lot development phase. A qualified member(s) of the builder's team should be onsite as these activities progress to ensure that each objective is achieved according to targeted green lot specifications.

Additional Information / How to Implement:

Information will be added in Version 2.

Resources:

Information will be added in Version 2.

Create a checklist to be completed onsite that contains only those targeted green development practices that will be implemented in the project.

Intent:

A qualified member(s) of the builder's team should be onsite as these activities progress to ensure that each objective is achieved according to targeted green lot specifications. A checklist will facilitate the process of tracking progress.

Additional Information / How to Implement:

Information will be added in Version 2.

Resources:

Information will be added in Version 2.

2.0 Select the site.

Select the site to minimize environmental impact.

Avoid environmentally "sensitive areas" as identified through site foot printing process or third party.

Intent:

Thoughtful site selection can be the first step in building a green home. By avoiding environmentally sensitive areas, a builder can help preserve land that might function as a wildlife corridor, recreational open space, or habitat sanctuary. If a site is selected that, at any time, has been identified as an environmentally "sensitive area," no credit will be given for this line item, regardless of the site's classification at the time of construction.

Additional Information / How to Implement:

"Sensitive areas" may be identified within a comprehensive plan, by a wetland institute, or by the local jurisdiction. Other excellent sources of detailed environmental information about a site are professionals such as arborists, landscape architects, ecologists, and wildlife biologists. These experts can provide assistance in identifying a potential site's natural resources and environmentally sensitive areas.

Resources:

- American Society of Consulting Arborists, http://www.asca-consultants.org/why.html.
- American Society of Landscape Architects, http://www.asla.org/members/pigroups.cfm.
- International Society of Arboriculture, http://www.isa-arbor.com/home.asp.
- Society of American Foresters, http://www.safnet.org/certifiedforester/.
- The Ecological Society of America, http://www.esa.org/.
- Choose an EPA recognized Brownfield.

Intent:

Remediation of a Brownfield results in the environmental restoration of a polluted site, a transformation that makes an abandoned site habitable. Like Greyfield and infill development, Brownfield development provides an efficient use of land and infrastructure while allowing for the preservation of open space and wildlife habitat in the midst of growth.

Additional Information / How to Implement:

The U.S. Environmental Protection Agency (EPA) characterizes Brownfields as "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." The EPA estimates that there are 450,000 Brownfield sites around the country. Grants, loans, and training are available through the EPA's Brownfield Initiative to assist builders and developers in the remediation and development of Brownfield sites.

Resources:

- U.S. EPA, *Brownfields Cleanup and Redevelopment*: http://www.epa.gov/Brownfields/index.html.
- U.S. EPA has introduced two Web-based tools to give the public additional access to information about Brownfield properties and cleanup efforts. The tools allow residents to locate Brownfields and provide access to information about cleanup grants - www.epa.gov/Brownfields/bfwhere.htm

Choose a Greyfield site.

Intent:

Redevelopment of a Greyfield site can provide an efficient use of land and infrastructure. Greyfield redevelopment allows for the preservation of open space and wildlife habitat in the midst of growth.

Additional Information / How to Implement:

Within these guidelines, a Greyfield is defined as "any site previously developed with at least 50% of the surface area covered with impervious material." The development of a Greyfield site can be daunting, but local or national incentives may exist to reward builders who go through the process. Incentives may include the elimination of development related fees, contribution from the local government in the development of off-site improvements, and tax breaks. For more information, see Resources.

Resources:

- Congress for the New Urbanism, http://www.cnu.org.
- Urban Land Institute, http://www.uli.org.
- American Planning Association, http://www.planning.org.
- International Council of Shopping Centers, http://www.icsc.org.
- Congress for the New Urbanism and PricewaterhouseCoopers, *Greyfields into Goldfields: from falling shopping centers to great neighborhoods* (February 2001), http://www.cnu.org/cnu_reports/Executive_summary.pdf.

- Congress for the New Urbanism and PricewaterhouseCoopers, *Greyfield Regional Mall Study* (January 2001), http://www.cnu.org/cnu_reports/Greyfield_Feb_01.pdf.

Choose an infill site.

Intent:

Building on an infill site can effectively conserve resources (e.g., infrastructure) and preserve open space that could be lost from "green field" development.

Additional Information / How to Implement:

Infill areas are vacant or underutilized lots of land, served by existing physical installations such as roads, power lines, sewer and water, and other infrastructure.

Resources:

- Policy Link, Equitable Development Toolkit, Infill Incentives, http://www.policylink.org/EDTK/Infill/.
- Northeast-Midwest Institute and Congress for the New Urbanism, *Strategies for Successful Infill Development* (2001), http://www.nemw.org/infillbook.htm.

3.0 Design the site

Minimize environmental impacts; protect, enhance, and restore the natural features and environmental quality of the site.

Conserve natural resources.

1. Complete a natural resources inventory that is used to drive/create the site plan.
2. Create a protection and maintenance plan for priority natural resources/areas during construction. See Section 4 for guidance in forming the plan.
3. Locate roads, buildings, and other built features to conserve high priority vegetation.
4. Participate in a natural resource conservation program.

Intent:

Onsite natural resources concern features such as solar energy availability, flora, fauna, water, soil, and geological formations. A natural resources inventory should be completed to identify the site's environmental attributes. Based on this inventory, a builder can identify high priority resources for conservation (e.g., trees, waterway, snags, micro-habitats) and plan for the conservation of those resources during each stage of site development.

Information / How To Implement:

On complex sites, a natural resources inventory may be performed by a qualified professional such as an arborist, wildlife biologist, or landscape architect. Simpler sites, such as previously developed sites or farmland, might be adequately inventoried by knowledgeable, but less qualified individuals. Whoever ultimately conducts the inventory should be able to discern between invasive and regionally appropriate vegetation, understand how to site a house to take advantage of solar energy, be able to identify areas important to wildlife habitat, and understand how natural features can be used in managing storm water onsite.

A protection and maintenance plan should be drafted to detail how resources identified through the inventory will be protected throughout development. Section 4 of this module provides details on how to protect existing onsite vegetation and minimize soil disturbance and erosion through installation of fencing, identification of specified washout and material storage areas, laying of mulch to reduce soil compaction, and other means. In addition to protecting priority areas from invasive species intrusion during development, a maintenance plan should be created to ensure that priority vegetation survives development. Within the maintenance plan, include plans and information on fertilizing and watering trees as needed before, during, and after development.

One way to verify that the plan is implemented as planned is to create construction documents that explain how to implement the plan during construction.

Resources:

- American Society of Consulting Arborists, http://www.asca-consultants.org/why.html.
- American Society of Landscape Architects, http://www.asla.org/members/pigroups.cfm.
- International Society of Arboriculture, http://www.isa-arbor.com/home.asp.
- Society of American Foresters, http://www.safnet.org/certifiedforester/.

Orient streets and configure lots to allow for the majority of homes to optimize solar potential (see the Energy Efficiency Module for guidance on solar resource optimization).

Intent:

Thoughtful orientation of a home can maximize solar heating potential in the heating season and minimize solar gains in the cooling season. By reducing non-renewable energy needs, orienting a home to optimize the solar resource reduces the life cycle pollution caused by a home.

Information / How to Implement:

There are many factors to consider when siting a home. A builder should consider such issues such as slope, storm water management, local solar angles, and high priority vegetation in determining the optimum site for each home. The final decision in siting a home will generally involve a compromise between these many factors.

Resources:

See Section 3.4 of this User Guide for resources.

Minimize slope disturbance.

1. Limit development footprint on steep slopes (slopes greater than or equal to 25%).

2. Complete a hydrological/soil stability study for steep slopes and use this study to guide the design of all structures onsite.
3. Align roads with natural topography to minimize its grade to reduce cut and fill.
4. Reduce long-term erosion effects through the design and implementation of terracing, retaining walls, and re-stabilization techniques.

Intent:

Leaving a slope undisturbed when siting a home reduces the chances of disturbing natural hydrological drainage and causing long and short term erosion, thereby reducing the potential to pollute water sources and damage local ecology.

Additional Information / How to Implement:

Within these guidelines, steep slopes are defined as being greater than or equal to 25%. Note: points should only be awarded if there are developable steep slopes in the area.

Reducing cut and fill practices can prevent unnecessary stripping of vegetation and loss of soils and reduce the need for additional resources to be brought in from off-site.

Resources:

- Prince George's County, Maryland, Department of Environmental Resources, *Low-Impact Development Design Strategies: An Integrated Design Approach* (EPA 841-B-00-003) (Largo, MD: June 1999), http://www.epa.gov/owow/nps/lid/lidnatl.pdf.

Minimize soil disturbance and erosion.

- 1. Phase development in order to minimize exposed soils.
- 2. Use alternative means to install utilities, such as tunneling instead of trenching. Use smaller equipment, shared trenches or easements, and place utilities under streets instead of yards.

Intent:

Sediment and pollutants contained in the sediment are recognized as a reason that water bodies do not meet their intended uses. Exposed soils should be minimized to reduce erosion, promote water quality, and reduce damage caused to native vegetation. Heavy equipment and excessive digging can result in compaction or loss of topsoil along with the introduction of invasive and problematic flora. By minimizing soil disturbance and erosion you can both reduce stressors on downstream water bodies and you can save valuable topsoil for the site.

Additional Information / How to Implement:

NAHB's Storm Water Permitting: A Guide for Builders and Developers contains information about the federal Phase I and II storm water permitting program and the equivalent requirements for state storm water permits (see Resources section). Storm Water Permitting also contains technical information, including recommendations for use and cost estimates, on over 50 of the most commonly used Best Management

Practices; sample Storm Water Pollution Prevention Plans; and tips on compliance, including how to handle visits from inspectors.

Methods for preventing erosion include silt fences, sediment traps, vegetated buffer areas, and mulching. More permanent solutions include biomechanical devices such as swales and vegetated buffers. Another highly effective, environmentally responsible method to preventing erosion is to use compost filter berms, compost erosion socks and/or surface application of compost erosion control. The compost should be from organic sources like bioshields, yard waste, and wood chips. Turf and plant material - which help to facilitate the reestablishment of a natural environment – are established more quickly when organic compost is used.

Resources:

- National Association of Home Builders (NAHB), Storm Water Permitting: A Guide for Builders and Developers, 2004, http://store.builderbooks.com or 800-368-5242 x8163
- King County Department of Natural Resources, King County, *Washington Surface Water Design Manual Appendix D: Erosion and Sediment Control Standards* (Seattle: September 1998), ftp://ftp.metrokc.gov/ddes/acrobat/esa/kcswdm-d.pdf.
- Dr. James R. Fazio, National Arbor Day Foundation, *Trenching and Tunneling: A Pocket Guide for Qualified Utility Workers* (Nebraska City, Nebraska: 1998), http://www.arborday.org/shopping/merchandise/merchdetail.cfm?id=62.

Manage storm water properly.

1. Direct storm water to a locally approved regional storm water management and treatment facility that has been designed to address water quality.
2. Preserve and utilize natural water and drainage features.
3. Develop and implement storm water management plans that minimize concentrated flows and seek to mimic natural hydrology.
4. Minimize impervious surfaces and utilize permeable materials for
    a. Parking areas
    b. Walkways
    c. Minimize street widths and rights-of-way as per recommendations in either local code or in Residential Streets, 3rd Edition:
        i. No on-street parking: 18 feet
        ii. Parking on one side: 22 – 24 feet
        iii. Parking on both sides: 24 – 26 feet

Intent:

Percolation through soil is one of the most effective means for filtering pollutants carried by storm water. By using natural water and drainage features, minimizing impervious surfaces, and distributing storm water flows, builders can reduce harmful pollutants carried off site while safely and effectively managing much of their storm water load onsite.

Additional Information / How to Implement:

Use open space and natural systems such as vegetative swales, french drains, wetlands, drywells, and rain gardens that promote water quality and infiltration.

Resources:

- The Practice of Low Impact Development, U.S. Department of Housing and Urban Development (HUD); http://www.huduser.org/publications/destech/lowimpactdevl.html
- Tom Schueler, Center for Watershed Protection, *Site Planning for Urban Stream Protection,* Ellicott City, MD, 1995, http://www.cwp.org/SPSP/TOC.htm.
- Lisa Austin, Washington State Department of Ecology Water Quality Program, S*tormwater Management Manual for Western Washington* (Publication 99-12), September 2001, http://www.ecy.wa.gov/pubs/9912.pdf.
- Betty Rushton, Southwest Florida Water Management District, *Low Impact Parking Lot Design Reduces Runoff and Pollutant Loads: Annual Report # 1.*, Brooksville, Florida, 1999.

Where municipal sewage is not available, use an advanced wastewater system as an alternative to the conventional septic system and drain field. Examples include sand/media filters and aerobic treatment units.

Intent:

Refer to the Water Efficiency section of the User Guide for details on this topic.

Additional Information / How to Implement:

Information will be added in Version 2.

Resources:

Information will be added in Version 2.

Devise landscape plans to limit water demand while preserving or enhancing the natural environment.

1. Formulate a plan to restore or enhance natural vegetation that is cleared during construction or development. Within this plan, phase landscaping to ensure denuded areas are quickly vegetated.
2. Select turf grass and other vegetation that are native or regionally appropriate species.
3. Limit turf areas of landscaped area, selecting native and regionally appropriate trees and vegetation in a way that complements the natural setting.
4. Group plants with similar watering needs (hydro-zoning).

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5. Specify planting of trees to increase site shading and moderate temperatures (see also Energy Efficiency guideline 3.3.5.1 specifying sitting of trees to reduce the energy consumption of the home).
6. Require onsite tree trimmings of regionally appropriate species to be used as protective mulch during construction or as a base for walking trails.
7. Establish an integrated pest management plan to minimize chemical use in pesticides and fertilizers.

Intent:

Landscaping water use accounts for approximately 50% of a home's total water needs. Conservation of this valuable resource through such techniques as hydrozoning, reducing turf area, and selecting regionally appropriate plants is a key component to responsible building. Thoughtful selection and placement of plants can also reduce heating/cooling loads of a home, provide habitat for native fauna, and minimize the heat-island effect of developments.

Additional Information / How to Implement:

Select landscaping materials and vegetation to fit site conditions. Regionally appropriate plants are hardy plants that can withstand local water and temperature conditions such as freeze, heat, drought, and rain. Regionally appropriate plants will also not be overly prolific or invasive, and will be able to coexist with other native plants over time.

Other benefits of landscaping with native plants: minimizes maintenance (reduces emissions of equipment); fosters wildlife habitat. See EPA's Mid-Atlantic Region Green Landscaping http://www.epa.gov/reg3esd1/garden/what.htm for more information.

When planning for the revegetation of a site, consider the multiple services that natural areas can provide: natural habitat, storm water processing, shading, wind break, etc. Trees that shade the streets can keep a neighborhood cool while also increasing the neighborhood's attractiveness. Properly selected plants can be grouped to serve as a bioretention zone. Deciduous trees allow the sun's rays through in winter and provide shade in the summer. Evergreens can provide an effective windbreak. Careful selection and integration of trees and vegetation can reduce a developer's initial costs while providing value to a development/neighborhood later. When planting trees, several factors should be taken into account such as the value of shading (trees shading asphalt will mitigate a site's temperature more than trees shading landscaped areas), maintaining a safe distance from the house (especially in areas prone to natural disasters), ultimate tree size, etc.

Developers may wish to consider enforcing guidelines for the protection of onsite vegetation. Some developers even fine builders for damage to areas designated for protection.

If grinding and scattering cleared plants, care should be taken to grind only regionally appropriate plants. Grinding of invasive species can increase their propagation and result in the ultimate destruction of native species.

One of the best ways to reduce energy consumption is through passive solar design of a home – using orientation, overhangs, fenestration, etc. Landscaping to reduce energy consumption is only part of the whole effort.

It is good practice to limit the ratio of turf area to total landscaped area due to maintenance requirements of turf versus native plants and regionally appropriate vegetation. In some areas, there may be restrictions on the percentage of turf that the front yard must contain. Research has shown that homeowners are comfortable with having as little as 50% of the front yard composed of turf. Fewer regulations are imposed on turf-to-landscaping ratio in the backyard, so good gains might be made more easily there. For research on turf and landscape of front yard with native species, see: Nassauer, Joan, 1995. *Messy Ecosystems, Orderly Frames*. Landscape Journal, 14 (2), 161-170.

In areas with low annual rainfall, one way to account for water usage is through the development and implementation of a water budget.

Resources:

- Center for Plant Conservation, http://www.mobot.org/CPC/.
- Lady Bird Johnson Wildflower Center, Native Plant Information Network National Suppliers Directory, http://www.wildflower2.org/NPIN/Suppliers/suppliers.html.
- New England Wildflower Society, *Native Plant Societies of the United States and Canada,* http://www.newfs.org/nps.htm.
- NAHB Research Center Inc., Onsite Grinding of Residential Construction Debris: The Indiana Grinder Pilot, February 1999.

Maintain wildlife habitat.

1. Preserve open space as wildlife corridors where possible.
2. Submit evidence of wildlife habitat preservation and improvements to the green development guidelines' administrator for review.
3. Participate in a wildlife conservation program.

Intent:

As the frontier of home building continues to expand, sharing the land with wildlife becomes an increasing challenge to builders. Through individual initiative or participation in a wildlife conservation program, home builders can work to create a habitat where both wildlife and humans can thrive - whether in an urban, suburban, or rural setting.

Additional Information / How to Implement:

Examples of programs: USDA National Resources Conservation Service's Backyard Conservation Plan, the Audubon Cooperative Sanctuary System's Treasuring Home Initiative, or the National Wildlife Federation's Backyard Wildlife Habitat Program.

Enhance quality of habitat, including food sources, diversity of habitat, and protective areas, through selective plantings and site design.

Leave snags (dead tree or portion that's left for habitat). Bird houses.

Resources:

- Audubon International, *Audubon Cooperative Sanctuary System,* http://www.audubonintl.org/programs/acss/. Audubon Cooperative Sanctuary System's Treasuring Home Initiative. Is there certification available through this?
- Become a certified participant in the National Wildlife Federation's Backyard Wildlife Habitat Program. https://secure.nwf.org/backyardwildlifehabitat/certify/page1.cfm.

Prepare operation and maintenance plan (manual) for transfer of common open spaces, utilities (storm water, wastewater), and environmental management.

Intent:

Green land use features often require ongoing maintenance so that they can continue to function as designed. Planning for such operations and maintenance prior to implementing the features is important and can help the long-term viability of such features.

Additional Information / How to Implement:

Many manufacturers and distributors of green land use features and technologies also sell annual and/or long-term maintenance plans. Ask the manufacturers and/or distributors of the particular technology you're planning on implementing for such a service plan.

Resources:

Information will be added in Version 2.

Disassemble existing buildings and reuse or recycle the building materials (deconstruction) instead of demolishing.

Intent:

See the Resource Efficiency section for details on this topic.

Additional Information / How to Implement:

Information will be added in Version 2.

Resources:

Information will be added in Version 2.

4.0 Develop the site.

Minimize environmental intrusion during onsite construction

Provide onsite supervision and coordination during clearing, grading, trenching, paving, and installation of utilities to ensure that targeted green development practices are implemented.

Intent:

The noblest intentions when designing a green site are practically achieved through onsite supervision during the lot development phase. A qualified member(s) of the builder's team should be onsite as these activities progress to ensure that each objective is achieved according to targeted green lot specifications.

Additional Information / How to Implement:

The information for this line item should link to the plans and any documents produced in line item 1.3.5.

Resources:

Information will be added in Version 2.

Conserve existing onsite vegetation.

1. Provide basic training in tree and other natural resource protection to onsite supervisor.
2. Minimize disturbance of and damage to trees and other vegetation designated for protection through installation of fencing and avoidance of trenching, significant changes in grade, and compaction of soil and critical root zones.
3. Prepare designated existing trees and vegetation for the impacts of construction through pruning, root pruning, fertilizing, and watering.
4. Improve the soil with organic amendments and mulch.

Intent:

After a builder has identified (during the planning stage) the existing vegetation that will be conserved onsite, practical steps must be taken during the development stage to achieve the intended conservation. Such steps include pre-development preparation of the vegetation and protection of the foliage, soil, and root system of designated vegetation.

Additional Information / How to Implement:

See Resources section.

Resources:

- National Arbor Foundation, *Building With Trees,* http://www.arborday.org/programs/Buildingwithtrees/index.cfm.
- Phillip A. Pratt and Michael W. Schnelle, Oklahoma State University, Oklahoma Cooperative Extension Service, *Site Disturbance and Tree Decline* (OSU Extension Facts F-6429), September 2003, http://osuextra.com/pdfs/F-6429web.pdf.

Minimize onsite soil disturbance and erosion.

1. Demarcate limits of clearing and grading.
2. Create construction "no disturbance" zones using fencing or flagging to protect vegetation and sensitive areas from construction vehicles, material storage, and washout.
3. Install and maintain sediment and erosion controls.
4. Stockpile and cover good soil for later use.
5. Reduce soil compaction from construction equipment by laying mulch, chipped wood, or plywood sheets.
6. Stabilize disturbed areas within the 14-day period recommended by EPA.

Intent:

This guideline seeks to ensure the field implementation of conservation plans. Each measure identifies a practical way to foster water quality and conserve onsite ecological habitat through reducing soil disturbance and erosion.

Additional Information / How to Implement:

Soil stabilization may be temporary or permanent.

Keep in mind that, while the use of stockpiled onsite soil is a preferred method, excavation, stockpiling, grinding, and screening destroy the ecological microsystem of the soil. Rejuvenation of the unimproved soil to its original form will take several years. To offset this phenomenon, the incorporation of compost and sand is an effective method for more rapidly rebuilding the structure and ecosystem of the topsoil and allowing turf and plants to establish more quickly. As indicated above, compost is recommended for this purpose.

When additional soil must be brought in, there are environmental advantages of using industrial by-products as ingredients in topsoil including foundry sand, biosolids compost, and other EPA-approved by-products. In addition to keeping these materials out of community landfills, processing techniques produce superior topsoil.

The use of organic mulch is an excellent way to conserve water in landscape beds and build soil quality. Ideally, use mulch that results from onsite recycling efforts such as yard waste, processed pallets, and other clean wood from construction waste.

Resources:

- ❖ King County Department of Natural Resources, King County, *Washington Surface Water Design Manual Appendix D: Erosion and Sediment Control Standards* (Seattle: September 1998), ftp://ftp.metrokc.gov/ddes/acrobat/esa/kcswdm-d.pdf.

5.0 Innovative options

Seek to obtain waivers or variances from local development regulations to enhance green building.

Cluster development to preserve meaningful open space.

Intent:

Preserve meaningful open space and reduce infrastructure and long-term maintenance costs.

Additional Information / How to Implement:

During the last fifty years, a steady migration from urban to suburban areas and into the countryside has constituted a significant trend throughout much of the United States. In response to this phenomenon, planners, developers, and elected officials have created a number of tools designed to balance growth with the preservation of community environmental and financial assets. One tool that has received an increasing amount of attention lately is cluster development. This approach may be termed open-space development, conservation development, hamlet style, farm village, or other unique names coined by proponents and developers. Regardless of the title used to describe it, cluster development is an important tool community planners should consider as they look to the future. The purpose of this fact sheet is to describe cluster development, its history, potential, and limitations.

Resources:

- U.S. Environmental Protection Agency, Development, Community, and Environment Division, *Our Built and Natural Environments* (EPA 231-R-01-002) (Washington, DC: 2001), http://www.epa.gov/smartgrowth/pdf/built.pdf.
- Urban Land Institute, http://www.uli.org/DK/index.cfm?CFID=526893&CFTOKEN=67483350.

Reduce street widths.

Intent:

Reduce the amount of impervious surface and storm water runoff in the development.

Additional Information / How to Implement:

Street widths have the largest impact on runoff and on costs. Unfortunately, most communities have ordinances requiring excessively wide streets. Developers may be able to negotiate changes for a particular development, but will likely have to seek changes to local land development standards to change street width requirements more generally.

The publication, *Proposed Model Land Development Standards and Accompanying Model State Enabling Legislation* (HUD and NAHB Research Center, 1993), includes recommendations for minimum street widths that recognize the cost and environmental benefits of narrower versus wider streets (see below), and other cost-effective development strategies. It also includes recommendations for turnarounds, another location where the pavement area can be reduced.

Recommendations for Minimum Street Widths

Widths of Traveled Way
Minimum Width of Traveled Way (ft.)

Street Type	Both On- and Off-Street Parking (1)	One-Way Street (2)
Major Collector	20 (3)	10
Collector	36 (4)	26
Subcollector	26 - 28 (4, 5)	26
Access	18 - 22 (5)</SUP< p>	18

Where no off-street parking is provided, the minimum width of traveled way for collector streets shall be 36 feet, and 34 feet for subcollector and access streets (two 9- or 10-foot travel lanes and two 8-foot parking lanes). Major collectors do not typically accommodate on-street parking. Access street width can be reduced to 26 feet if parking needs are met on one side of the street and restricted to that side only.

Where on-street parking is not permitted, the one-way street width may be reduced to 10 feet.

Parking is not allowed on major collector streets. Travel lanes may be added in accordance with traffic requirements.

Width can be reduced to 20 feet if on-street parking is not permitted.

Minimum street width shall be selected by taking into consideration the size of fire and emergency equipment that will serve the development.

Resources:

- Better Site Design Fact Sheet: Narrower Residential Streets, http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/narrow_streets.htm

Install an advanced waste water treatment system.

Intent:

See the Water Efficiency section of the User Guide for more details on this topic.

Additional Information / How to Implement:

Information will be added in Version 2.

Resources:

Information will be added in Version 2.

Install an advanced storm water treatment system.

Intent:

Percolation through soil is one of the most effective means for filtering pollutants carried by storm water. By using natural water and drainage features, minimizing impervious surfaces, and distributing storm water flows, builders can reduce harmful pollutants carried off site while safely and effectively managing much of their storm water load onsite.

Additional Information / How to Implement:

This line item would be over and above what is done for line item 1.3.5. Use open space and natural systems such as vegetative swales, french drains, wetlands, drywells, and rain gardens that promote water quality and infiltration.

Resources:

- *The Practice of Low Impact Development*, U.S. Department of Housing and Urban Development (HUD); http://www.huduser.org/publications/destech/lowimpactdevl.html
- Tom Schueler, Center for Watershed Protection, *Site Planning for Urban Stream Protection* (Ellicott City, MD: 1995), http://www.cwp.org/SPSP/TOC.htm.
- Lisa Austin, Washington State Department of Ecology Water Quality Program, *Stormwater Management Manual for Western Washington* (Publication 99-12) (September 2001), http://www.ecy.wa.gov/pubs/9912.pdf.
- Betty Rushton, Southwest Florida Water Management District, *Low Impact Parking Lot Design Reduces Runoff and Pollutant Loads: Annual Report # 1.* (Brooksville, Florida: 1999).

Institute wildlife habitat measures.

Intent:

As the frontier of home building continues to expand, sharing the land with wildlife becomes an increasing challenge to builders. Through individual initiative or participation in a wildlife conservation program, home builders can work to create a habitat where both wildlife and humans can thrive - whether in an urban, suburban, or rural setting.

Additional Information / How to Implement:

Examples of programs include the USDA National Resources Conservation Service's Backyard Conservation Plan, the Audubon Cooperative Sanctuary System's Treasuring Home Initiative, and the National Wildlife Federation's Backyard Wildlife Habitat Program.

Enhance quality of habitat, including food sources, diversity of habitat, and protective areas, through selective plantings and site design.

Leave snags (dead tree or portion that's left for habitat).

Resources:

- Audubon International, *Audubon Cooperative Sanctuary System,* http://www.audubonintl.org/programs/acss/. Audubon Cooperative Sanctuary System's Treasuring Home Initiative.

- Become a certified participant in the National Wildlife Federation's Backyard Wildlife Habitat Program. https://secure.nwf.org/backyardwildlifehabitat/certify/page1.cfm.

Minimize grading.

Intent:

Excessive grading can disturb a site's natural drainage, vegetation, and ecological habitat. If top soil removed during grading is not replaced, the health of the site's future ecological system may be compromised as well.

Additional Information / How to Implement:

Information will be added in Version 2.

Resources:

Information will be added in Version 2.

Share driveways or parking

Intent:

Sharing driveways or parking can reduce the amount of impervious material on a lot, thereby decreasing storm water and pollution run-off.

Additional Information / How to Implement:

Information will be added in Version 2.

Resources:

Information will be added in Version 2.

Other (specify).

Information will be added in Version 2.

Low –Impact Development Design: A New Paradigm for Stormwater Management
Mimicking and Restoring the Natural Hydrologic Regime
An Alternative Stormwater Management Technology

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Abstract

Whether complying with federal or state regulations or addressing local vital watershed protection / restoration objectives, local jurisdictions are confronted with the daunting task of developing, administering and funding complex effective multi-objective stormwater management programs. Today's comprehensive stormwater program not only has to deal with runoff quantity and quality control but, may also have to address such complicated issues as ecosystem restoration, combined sewer overflow reduction, fisheries protection, potable surface / ground water source protection, and wetland, riparian buffer and stream protection. As our understanding of the technical and practical limitations of conventional stormwater management technology has increased over the past two decades, and as watershed protection objectives have changed, many jurisdictions have begun to question the efficacy and cost-effectiveness of conventional stormwater approaches in meeting today's complex environmental / water resources objectives. Older communities with existing extensive stormwater management infrastructures are also struggling with the economic reality of funding the high costs of maintenance, inspection, enforcement and public outreach necessary to support an expanding and aging infrastructure. Still more challenging are the exceptionally high costs of retrofitting existing urban development using conventional stormwater management end-of-pipe practices to restore and protect receiving waters and living resources.

With growing concerns about the limitations of conventional technology and to address the changing objectives of watershed protection, in 1990 Prince George's County's Department of Environmental Resources (PGDER) began exploring alternative stormwater management practices and strategies. The development of bioretention or "Rain Gardens" (using the green space to manage runoff within small depressed landscaped areas) lead to an understanding of how to optimize and engineer the landscape to restore hydrologic functions by uniformly integrating micro-scale management practices and impact minimization measures into the development landscape. In 1997 PGDER released the Low Impact Development (LID) Design Manual demonstrating the principles and practices of LID to create a hydrologically functional landscape.

LID stormwater management technology can maintain or restore a watershed's hydrologic regime by fundamentally changing conventional site design to create an environmentally and hydrologically functional landscape that mimics natural hydrologic functions (volume, frequency, recharge and discharge). This is accomplished in four ways. First: minimizing impacts to the extent practicable by reducing imperviousness, conserving natural resources and ecosystems, maintaining natural drainage courses, reducing the use of pipes and minimizing clearing / grading. Second: recreating detention and retention storage dispersed and evenly distributed throughout a site with the use of open swales, flatter slopes, depression storage, rain gardens (bioretention), water use (rain barrels), etc. Third: maintaining the predevelopment time of concentration by strategically routing flows to maintain travel time. Fourth: providing effective public education and socioeconomic incentives to ensure property owners use effective pollution prevention measures and maintain management measures. With LID, every site feature is multifunctional (green space, landscaping, grading, streetscapes, roads and parking lots) and helps to reduce stormwater impacts or provide / maintain beneficial hydrologic functions. The cumulative beneficial impact of using the wide array of distributed LID techniques allows the site designer to maintain or restore watershed's natural relationship between rainfall, runoff, infiltration and evaporation.

The effective use of LID site design techniques can significantly reduce the cost of providing stormwater management. Savings are achieved by eliminating the use of stormwater management ponds, reducing pipes, inlet structures, curbs and gutters, less roadway paving, less grading and clearing. Where LID techniques are applicable, and depending on the type of development and site constraints, stormwater and site development design

construction and maintenance costs can be reduced by 25 % to 30% compared to conventional approaches.

The creation of LID's wide array of micro-scale management principles and practices has lead to the development of new tools to retrofit existing urban development. Micro-scale management practices that filter, retain and detain runoff can be easily integrated into the existing green space and streetscapes as part of the routine maintenance and repair of urban infrastructure. LID retrofit techniques may lead to drastic reductions in the cost of retrofit existing urban development. Reducing urban retrofit costs will increase the ability of cities to implement effective retrofit programs to reduce the frequency and improve the quality of CSOs and improve the quality of urban runoff to protect receiving waters. LID represents a radically different approach to controlling stormwater runoff that provides effective tools to restore or maintain a watershed's hydrologic functions for new or existing development.

In 1998 EPA provided grant funding to assist PGDER in their efforts to develop a general manual describing LID's principles and practices and share this technology with other local governments throughout the nation. Efforts are currently underway with EPA to further advance LID technology by improving the sensitivity of current hydrology and hydraulic analytical models for application with small watersheds and sites and to develop new micro-scale control approaches and practices for urban retrofit. Additional efforts are also underway to demonstrate how LID micro-scale management and multifunctional infrastructure principles and practices can be used to control highway runoff within existing rights-of-way. It is hoped that the LID national manual will help to stimulate debate on the state of current stormwater, watershed protection and restoration technology and its future direction. The lessons learned about LID planning, principles, practices and research are described in detail in the reference documents 1 through 4 listed a the end of this paper. Copies of these reference documents can be obtained by calling the Prince George's County's Department of Environmental Resources at (301) 883-5832.

Background

Typically, adverse stormwater impacts are mitigated using conservation of natural resources (forests, streams, floodplains and wetlands); zoning restrictions to direct densities and increase open space; and the use of structural or non-structural control technologies (best management practices - BMP's) to treat and manage runoff quantity and quality. Many conventional stormwater mitigation approaches, such as management ponds, exhibit a number of inherent practical, environmental and economic limitations including inability to replicate predevelopment watershed hydrology, elevated water temperatures, costly maintenance burdens, and accelerated stream erosion due to the increased duration and frequency of runoff events. Furthermore, because current mitigation practices only lessen development impacts, there is concern about the cumulative impacts of the widespread use of conventional mitigation practices that may fundamentally alter a watershed's hydrologic regime and water quality, adversely affecting receiving waters and the integrity of their ecosystems. Many highly urbanized jurisdictions are beginning to question the efficacy of current technology and are finding it harder to ensure, enforce or fund stormwater programs and maintain the massive infrastructure created by conventional approaches.

Currently every site is designed with one basic overriding goal - to achieve good drainage. As we develop a site reshaping the landscape inch by inch, its hydrologic functions are altered on a micro-scale level. The cumulative impacts of micro-scale changes to the landscape drastically alter watershed hydrology. If sites can be designed to achieve good drainage, destroying natural hydrologic functions, why not design sites with the opposite objective to maintain predevelopment hydrologic functions? If inch by inch, sites are carefully and intelligently engineered to maintain hydrologic functions, would the cumulative beneficial affects result in the preservation of a watershed's hydrology? Can a site be designed in a way to remain as a functional part of a watershed's hydrological regime? To achieve a hydrologically functional development there must be a radical change in our thinking. We must not think in terms of impact mitigation as the stormwater management objective, but rather preservation of hydrologic and environmental functions. We should design sites to maintain hydrologic functions not just to mitigate impacts. Can our current stormwater management technology adequately meet our regulatory objectives and water resources / ecosystem protection needs? No one can answer that question for sure. However, it has not been shown that conventional ponds replicate predevelopment hydrology nor is there any evidence to suggest that conventional technology can ensure the ecological integrity of ecosystems. In fact, recent studies suggest that conventional approaches can not meet our water / living resources and ecological objectives.

Introduction

With growing concerns about the economics and efficacy of conventional technology, in 1990 Prince George's County Maryland's Department of Environmental Resources began exploring alternative stormwater management practices. The success that was achieved through the development and use of bioretention (filtering or infiltration runoff in small depressed landscaped areas) led to us first to an understanding that perhaps changing the form and function of the developed landscape could be important in mitigating urban stormwater impacts. Later it was realized that through intelligent site design and uniform distribution of LID micro-scale management controls that it was possible to maintain or restore hydrologic functions in a developed watershed. What is not known is how much of a watershed's hydrologic functions can be maintained or restored within a given development type (residential, commercial or industrial)? The one limiting factor to maintaining / restoring the hydrologic regime for highly urbanized development is the lack of available micro-management tools. Much of the current research underway is to expand the number of practices applicable in highly urbanized areas.

LID's objective is to reproduce the natural predevelopment hydrologic regime. If predevelopment hydrology and water quality can be maintained, this would provide the best level of protection possible to receiving waters and aquatic living resources. Experience over the last 20 years has demonstrated that maximizing the efficiency of conventional conservation measures and the use of conventional end-of-pipe stormwater management practices can not reasonably be used to restore watershed functions. What is needed is a new philosophical approach to site development, an approach that will allow the designer to retain a site's hydrologic functions.

The approach used in LID designs is really an old one. LID borrows its basic hydrologic principles from nature - uniform distribution of micro-management controls. In a natural setting, stormwater is controlled by a variety of mechanisms (interception by vegetation, small depression storage, channel storage, infiltration and evaporation) uniformly distributed throughout the landscape. LID mimics these mechanisms by uniformly distributing small infiltration, storage, and retention and detention measures throughout the developed landscape. What we soon began to see is that every development feature (green space, landscaping, grading, streetscapes, roads, and parking lots) can be designed to provide some type of beneficial hydrologic function.

Low - Impact Development General

LID controls stormwater at the source creating a hydrologically functional landscape that mimics natural watershed hydrology. Low impact development (LID) achieves stormwater management controls by fundamentally changing conventional site design to create an environmentally functional landscape that mimics natural watershed hydrologic functions (volume, frequency, recharge and discharge). LID uses four basic management planning and design principles. First: minimize impacts to the extent practicable by reducing imperviousness, conserving natural resources / ecosystems, maintaining natural drainage courses, reducing use of pipes and minimizing clearing and grading. Second: provide runoff storage measures dispersed uniformly throughout the landscape with the use of a variety of small decentralized detention, retention and runoff use practices such as bioretention, open swales and flatter grades. Third: maintain the predevelopment time of concentration by strategically routing flows to maintain travel time and control discharge. Fourth: implement effective public education and incentive programs to encourage property owners to use pollution prevention measures and maintain on-lot landscape management practices. A developed site can be designed to become a hydrologically functional part of the watershed with comprehensive and intelligent use of LID practices and principles.

LID Basic Site Planning Strategies

The goal of LID is to design the site in a way that mimics hydrologic functions. The first step is to minimize the generation of runoff (reduce the change in the runoff curve number (CN)). In many respects, this step is very similar to traditional techniques of maximizing natural resource conservation, limiting disturbance and reducing impervious areas. The major difference with LID is you must carefully consider how best to make use of the hydrologic soil groups and site topography to help reduce and control runoff. These considerations would include how to:

1) maintain natural drainage patterns, topography and depressions,
2) preserve as much existing vegetation as possible in pervious soils; hydrologic soil groups A and B,
3) locate BMP's in pervious soils; hydrologic soil groups A and B,
4) where feasible construct impervious areas on less pervious soil groups C and D,
5) disconnect impervious surfaces,
6) direct and disburse runoff to soil groups A and B,
7) flatten slopes within cleared areas to facilitate on lot storage and infiltration and
8) re-vegetate cleared and graded areas.

Where ground water recharge is particularly important (to protect well, spring, stream and wetland flows) it is important to understand the source and mechanisms for ground water recharge. When using the LID design concepts to mimic the hydrologic regime you must determine how and where ground water on the site is recharged and where necessary protect and utilize the recharge areas in the site design.

LID Hydrologic Analysis / Response

The objective of LID site design is to minimize, detain and retain the post development runoff volumes uniformly throughout the site close to the source to simulate predevelopment hydrologic functions. Widespread use and uniform dispersion of on lot small retention and/or detention practices to control both runoff discharge volume and rate is key to better replicating predevelopment hydrology. Using LID practices also produces runoff frequencies that are much closer to existing conditions than can be achieved by typical application of conventional BMP's. Management of both runoff volume and peak runoff rate is included in the design. This is in contrast to conventional end-of-pipe treatment that completely alters the watershed hydrology regime.

The LID site analysis and design approach focuses on four major hydrologically based planning elements. These fundamental factors affect hydrologic and are introduced below.

- Curve Number (CN)- A factor that accounts for the effects of soils and land cover on amount of runoff generated. Minimizing the change in the post development CN by reducing impervious areas and preserving more trees and meadows to reduce runoff storage requirements all to maintain the predevelopment runoff volume.

- Time of Concentration (Tc) - This is related to the time runoff travels through the watershed. Maintaining the predevelopment Tc reduces peak runoff rates after development by lengthening flow paths and reducing the use of pipe conveyance systems.

- Permanent storage areas (Retention) - Retention storage is needed for volume and peak control, water quality control and to maintain the same CN as the predevelopment condition.

- Temporary storage areas (Detention) - Detention storage may be needed to maintain the peak runoff rate and/or prevent flooding.

Minimizing the Change in Curve Number CN

Reducing the change in CN will reduce both the post development peak discharge rate and volume. Calculation of the LID CN is based on a detailed evaluation of the existing and proposed land cover so that an accurate representation of the potential for runoff can be obtained. This calculation requires the engineer/ planner to

investigate the following key parameters associated with LID including:
1) land cover type,
2) percentage of and connectivity of impervious cover,
3) hydrologic soils group (HSG), and
4) hydrologic conditions (average moisture or runoff conditions).

The following are some of the LID site planning practices that can be utilized to achieve a substantial reduction in the change of the calculated CN:
1) narrower driveways and roads (minimizing impervious areas),
2) maximized tree preservation and/or afforestation,
3) site finger-printing (carefully siting lots / roadways to avoid disturbance of streams, wetlands and other resources), greater use of open drainage swales,
4) preservation of soils with high infiltration rates to reduce CN,
5) location of BMP's on high-infiltration soils and,
6) construction of impervious features on soils with low infiltration rates.

Maintaining the Predevelopment Time of Concentration Tc

The LID hydrologic evaluation requires that the post development Tc be close to the predevelopment Tc. Minimizing the change in pre and post Tc will help maintain the same frequency of runoff discharges assuming there is uniform distributed micro-scale retention and detention of LID practices. The following are some of the site planning techniques can be used to maintain the existing Tc:
1) maintain predevelopment flow path length by dispersing and redirecting flows using open swales and vegetated drainage patterns,
2) increase surface roughness (e.g., preserving woodlands, vegetated swales),
3) detaining flows (e.g., open swales, rain gardens, rain barrels etc.),
4) minimize disturbances (minimizing soil compaction and changes to existing vegetation /drainage patterns),
5) flatten grades in impacted areas,
6) disconnecting impervious areas (e.g., eliminating curb/gutter and redirecting down spouts) and,
7) connect pervious areas to vegetated areas (e.g., reforestation, afforestation).

The combined use of all these techniques results in cumulative impacts that modify runoff characteristics to effectively shift the post development peak runoff time and frequencies to that of the predevelopment condition, and lower the peak runoff rate.

Maintaining the Redevelopment Curve Number and Runoff Volume

Once the post development Tc is maintained at the predevelopment conditions and the impact of CN is minimized, any additional reductions in runoff volume must be accomplished through distributed micro-scale on-site stormwater management techniques. The goal is to select the appropriate combination of management techniques that simulate the hydrologic functions of the predevelopment condition to maintain the existing CN and corresponding runoff volume. The target design volume is equal to the initial abstraction of rainfall that would have occurred in the predevelopment condition. LID site designs maximize the use of small retention practices distributed throughout the site at the source to provide the required volume storage. The required storage volume will be reduced when the change in the pre and post CN is minimized.

Retention storage allows for a reduction in the post development volume and the peak runoff rate. The increased storage and infiltration capacity of retention LID BMP's allow the predevelopment volume (initial abstraction) to be maintained. The most appropriate retention BMP's include:
1) bioretention cells (rain gardens),
2) infiltration trenches,
3) water use storage (rain barrels and gray water uses) and,
4) roof top storage.

Other possible retention BMP's include retention ponds, cisterns and irrigation ponds but it may be difficult to distribute these types of controls throughout a development site.

As retention storage volume is increased there is a corresponding decrease in the peak runoff rate in addition to runoff volume reduction. If a sufficient amount of runoff is stored, the peak runoff rate may be reduced to a level at or below the predevelopment runoff rate. This storage may be all that is necessary to control the peak runoff rate when there is a small change in CN. However, when there is a large change in CN, it may be less practical to achieve flow control using volume control only.

Potential Requirement for Additional Detention Storage

In cases where very large changes in CN cannot be avoided, retention storage practices alone may be either insufficient to maintain the predevelopment runoff volume or peak discharge rates or require too much space to represent a viable solution. In these cases, additional detention storage will be needed to maintain the predevelopment peak runoff rates. A number of traditional detention storage techniques are available that can be integrated into the site planning and design process for a LID site. These techniques include:

1) swales with check dams, restricted drainage pipes, and inlet / entrance controls,
2) wide low gradient swales,
3) rain barrels / cisterns,
4) rooftop storage and
5) shallow parking lot / road storage.

Determination of Design Storm Event

The hydrologic approach of LID is to retain the same amount of rainfall within the development site as was retained prior to any development (e.g., woods or meadow in good condition) and then release runoff as the woods or meadow would have. By doing so, it is possible to mimic, to the greatest extent practical, the predevelopment hydrologic regime to maximize protection of receiving waters, aquatic ecosystems and ground water recharge. This approach allows the determination of a design storm volume that is tailored to the unique soils, vegetation and topographic characteristics of the watershed. This approach is particularly important in watersheds that are critical for ground water recharge to protect stream / wetland base flow and ground or surface water supplies.

LID BMP's

Site design techniques and BMP's can be organized into three major categories as follows; 1) runoff prevention measures designed to minimize impacts and changes in predevelopment CN and Tc, 2) retention facilities that store runoff for infiltration, exfiltration or evaporation and 3) detention facilities that temporarily store runoff and release through a measured outlet. **Table 1**, below lists some of a wide array of possible LID BMP's and their primary functions. Placing these BMP's in series and uniformly dispersing them throughout the site provides the maximum benefits for hydrologic controls.

Table 1. Examples of LID BMP's and Primary Functions

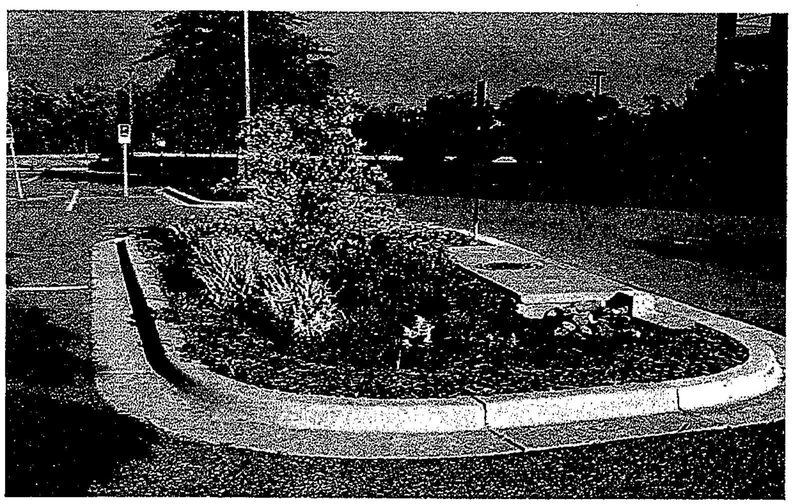
BMP	Runoff Prevention	Detention	Retention	Conveyance	Water Quality
Bioretention		X	X		X
Infiltration Trench			X		X
Dry Wells		X	X		

Roof Top Storage		X	X		X
Vegetative Filter Strips				X	X
Rain Barrels		X	X		
Swale and Small Culverts		X		X	X
Swales		X		X	X
Infiltration Swale		X	X	X	X
Reduce Imperviousness	X				
Strategic Clearing / Grading	X				
Engineered Landscape	X				
Eliminate Curb and Gutter	X				X
Vegetative Buffers	X				X

Water Quality

LID maximizes the use of the developed landscape to treat stormwater runoff. Not only can the landscape be used to store, infiltrate and detain runoff, the unique physical, chemical and biological pollutant removal / transformation / immobilization / detoxification capabilities of the soil, soil microbes and plants can be used to remove contamination from runoff. For example, bioretention basins or rain gardens are designed to use the upland soil /microbe /plant complex to remove pollutants from runoff. Rain gardens which look and function like any other garden except they treat runoff are designed with a layer of 2 - 3 inches of mulch, 2 –3 feet of planting soil and vegetation (trees shrubs and flowers). **Figure1** shows a parking lot landscape island rain garden (bioretention practice) that uses a high rate filter media with plants to filter and treat 90% of the annual volume of runoff from the parking lot.

Figure 1.Parking Lot Rain Garden



Studies conducted by the University of Maryland have shown rain gardens to be very effective in removing pollutants. The percent pollutant removal of various contaminants are shown below in **Table 2.** The results shown represent the average removal rates under a wide variety of flow rates and pollutant concentrations.

Table 2. Percent Pollutant Removal by Rain Gardens

Cu %	Pb %	Zn %	P %	TKN %	NH_4^+ %	NO_3^- %	TN* %
93	99	99	81	68	79	23	43

* Removal varied as a function of depth in the soil. Percent removal shown is at a depth of approximately 3 feet.

Testing Conducted by the University of Maryland, Department of Engineering

The variety of physical, chemical and biological pollutant removal mechanisms available in the complex rain garden system is staggering. A description or explanation in any detail of these mechanisms is beyond the scope of this paper. A more detailed description can be found in the 1998 "Optimization of Bioretention Design" study conducted by the University of Maryland. Mulch has been found to be very effective in removing heavy metals through organic complexing with the hydroxyl and carboxyl sites on the organic molecules. Soil bacteria can metabolize (use as a carbon energy source) oil, grease and gasoline into $C0_2$ and water in the presence of adequate nutrients and oxygen. Soil bacteria have been used for years for the remediation of contaminated soils. Plants are known to uptake, transpire, accumulate and detoxify heavy metals and many other toxic compounds. The physiologic and metabolic processes of plants are used to clean contaminated soils through phytoremediation. A goal of LID is to maximize the use of upland landscape with its soil/ microbes/ plant complex to treat runoff. Using upland systems to trap and remove pollutants allows one to more easily control the fate of contaminants and prevent them from entering the water column where they are almost impossible to contain and remove.

Public Outreach and Pollution Prevention

Pollution prevention and maintenance of on-lot LID BMP's are two key elements in a comprehensive approach. Effective pollution prevention measures can reduce the introduction of pollutants to the environment and extend the life of LID treatment BMP's. Public education is essential to successful pollution prevention and BMP maintenance. Not only will effective public education complement and enhance BMP effectiveness, it can also be used as a marketing tool to attract environmentally conscious buyers, promote citizen stewardship, awareness and participation in environmental protection programs and help to build a greater sense of community based on common environmental objectives and the unique character of LID designs.

Costs

LID case studies and pilot programs show that at least a 25% reduction in both site development and maintenance costs can be achieved by reducing grading and the use of pipes, ponds, curbs and paving. In one subdivision called Somerset which used the rain garden LID technique for water quality controls, the developer saved $4,500 per lot or a total of $900,000 by eliminating the need for curbs, ponds and drainage structures. Maintenance costs are also reduced in scale and magnitude by using the small LID practices. LID site designs require only routine landscape care and maintenance of the vegetation. This eliminates the high costs of pond maintenance associated with dam repairs and dredging.

Road Blocks to LID

In the development and acceptance of the LID site planning approach, a number of roadblocks had to be overcome. Regulating agencies, the development community and the public all had concerns about the use of new technology. The LID design manual represents the culmination of four years of work to address all of these concerns and issues. Some of the major components of the LID approach, which addressed the many concerns, include:

1) development of an hydrologic analytical methodology to demonstrates the equivalence of LID to conventional approaches,
2) development of new road standards which allow for narrow roads, open drainage and cluster techniques,
3) streamlining the review process for innovative LID designs which allow easy modification of site, subdivision, road and stormwater requirements,
4) development of a public education process which informs property owners on how to prevent pollution and maintain on lot BMP,
5) development of legal and educational mechanisms to ensure BMP's are maintained,
6) demonstrate the marketability of green development,

7) demonstrate the cost benefits of the LID approach,
8) provide training for regulators, consultants, public and political leaders and,
9) conduct research to demonstrate the effectiveness of bioretention BMP's.

Summary

LID is a viable economically sustainable alternative approach to stormwater management and the protection of natural resources. LID provides tangible incentives to a developer to save natural areas and reduce stormwater and roadway infrastructure costs. LID can achieve greater natural conservation by using conservation as a stormwater BMP to reduce the change in CN. As more natural areas are saved, less runoff is generated and stormwater management costs are reduced. This allows multiple use and benefits (environmental and economical) of the resource.

Additionally, developers have incentives to reduce infrastructure costs by reducing impervious areas, and eliminating curbs / gutters and stormwater ponds to achieve LID stormwater controls. Reduction of the infrastructure also reduces infrastructure maintenance burdens making LID designs more economically sustainable. Superior protection of aquatic and riparian ecosystems can be achieved since a LID developed watershed functions in a hydrologically similar manner as the predevelopment conditions. Recreating the predevelopment hydrological regime is a better way to protect the receiving waters than the conventional end-of-pipe mitigation approaches.

LID promotes public awareness, education and participation in environmental protection. As every property owner's landscape functions as part of the watershed, they must be educated on the benefits and the need for maintenance of the landscape and pollution prevention. LID developments can be designed in a very environmentally sensitive manner to protect streams, wetlands, forest habitat, save energy, etc. The unique character of a LID green development can create a greater sense of community pride based on environmental stewardship.

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Waterways at Risk

How Low-Impact Development Can Reduce Runoff Pollution in Michigan

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PIRGIM Education Fund

Bringing Rivers to Life

American Rivers

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Executive Summary

Many communities in Michigan are developing in ways that create water quality problems in the Great Lakes and inland waterways.

Runoff from developed land contaminates waterways with pollution after rainstorms. Construction of roads and buildings replaces natural surfaces that store and clean rainwater with hard, impervious surfaces (like pavement) that divert water and pollution directly into creeks or into sewers. As a result, community growth can lead to higher levels of contaminated runoff, impaired drinking water quality, degraded wildlife habitat and uncontrolled sewage overflows.

One quarter of Michigan watersheds are impacted by or vulnerable to contaminated runoff from developed land.

- 5 percent of Michigan watersheds are impacted, with more than 15 percent of their land area covered by pavement and other impervious surfaces.
- Another 4 percent are moderately impacted, with between 10 and 15 percent impervious cover; and
- 15 percent of Michigan's watersheds are vulnerable to developing significant water quality problems as a result of expanded development, with between 5 and 10 percent impervious cover as of 2001. (See Figure ES-1.)
- According to a 2001 forecast, Michigan will add over 4 million acres of new development by 2040, nearly tripling the amount of built land. Development on this scale threatens to pollute inland waterways and increase downstream impacts in the Great Lakes.

Watersheds in rapidly developing communities are most at risk, including areas surrounding Detroit and Grand Rapids, plus smaller areas near Kalamazoo, Lansing and Traverse City.

Municipalities that issued more than 200 building permits for single family homes in 2004 and occupy watersheds vulnerable to water quality decline include:

- **Southwest Detroit Metro Area:** Ann Arbor, Ypsilanti, Superior, Canton, Van Buren, Romulus, Huron, Brownstown and Bedford;
- **Northwest Detroit Metro Area:** Clinton, Sterling Heights, Troy, Chesterfield, Macomb, Shelby,

Figure ES-1: Impervious Cover in Michigan Watersheds

Impacted (>15 Percent impervious) | Moderately Impacted (Between 10 and 15 percent impervious) | Vulnerable (Between 5 and 10 percent impervious)

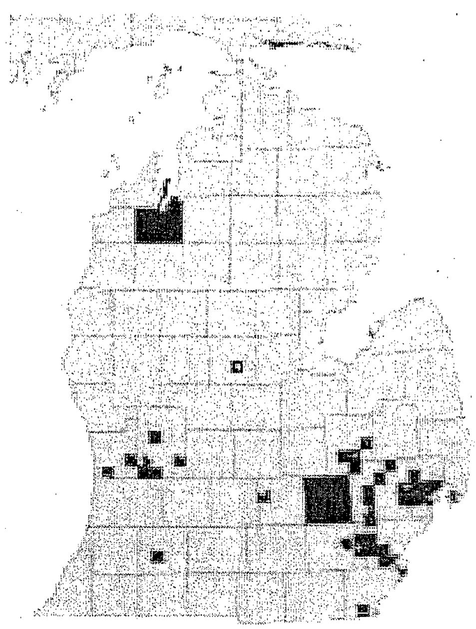
Rochester Hills, Washington, Oxford, Independence, White Lake, Commerce, Novi, Northville, Davison, Grand Blanc, Holly, Mundy, Brighton and unincorporated Livingston County;

- **Grand Rapids Area:** Lowell, Plainfield, Gaines, Byron, Wyoming, Georgetown and Holland;
- **Additional Areas:** Portage, Delhi, Union, and Grand Traverse County. (See Figure ES-2.)

Poorly designed development can cause water pollution, but development using innovative low-impact development and smart growth principles can greatly reduce runoff and prevent harm.

- Poorly designed developments treat stormwater runoff as a waste product, creating more runoff at a given site by using gutters and drains to dispose of runoff in ponds, creeks and sewers. The problem is aggravated by sprawling growth patterns that create larger amounts of runoff for a given number of residents. For example, a community of low-density development with a large network of roadways along a river will impact a larger area and cause greater amounts of runoff than a high-density, low-impact development, while disrupting the natural water cleaning ability of the land around the waterway.
- In contrast, low-impact development techniques replicate the natural functions of the environment on-site, using green spaces, native landscaping, and a variety of other simple, cost-effective and low-tech methods to capture and treat stormwater close to where it falls. In addition, smart growth practices reduce the area of impact and protect critical parts of

Figure ES-2: Rapidly Developing Areas At Risk of Water Quality Decline



the ecosystem by using strategic open spaces, infill development and redevelopment, and clustered, higher-density design—minimizing runoff in the aggregate.

Local governments have the power to promote smart growth and low-impact development.

Local governments can protect and restore local waterways by establishing riparian buffer zones, requiring no net runoff from new developments and implementing smart growth strategies. These policies can be included in community master plans and stormwater management plans, and included as legal requirements in zoning ordinances. Local governments should:

- Establish a natural buffer zone around creeks, streams or rivers. The state of New Jersey applies a 150- to 300-foot buffer zone to protect valuable drinking water supplies and their upstream headwaters.
- Change zoning policy in areas outside the urban core to require no net runoff from new developments. On-site measures should be capable of replicating pre-development runoff rates during a 2-year, 24-hour storm.
- Allow more flexibility in zoning policy to accommodate low-impact development principles. For example, zoning rules with strict requirements for wide streets or traditional stormwater infrastructure should be modified to allow equally effective low-impact strategies.
- Initiate low-impact retrofit programs in urban core areas like Detroit, Grand Rapids, Flint, Saginaw and Lansing to mitigate the impact of existing development.
- Couple riparian buffers, "no net runoff" and retrofit policies with broader smart growth strategies, including incentives for clustered development around town centers, infill development and redevelopment, strategic open land preservation and coordinated planning across local and regional boundaries. A comprehensive approach to growth will magnify the benefit of individual policies—leading to cleaner water locally and in the Great Lakes.

Introduction: Restoring the Great Lakes Through Local Government

The Great Lakes and urban waterways in Michigan have suffered serious abuse since the first days of settlement. First forests were cleared, causing runoff and erosion. Then factories were built along rivers and lakeshore, complete with waste pipes leading directly to the water. Industrial pollution caused serious toxic contamination and declines in water quality, and a corresponding loss of plant and animal life. These trends continued unchecked until the environmental regulations of the late 1960s and early 1970s—especially the Clean Water Act of 1972—established limits on direct pollution of Michigan waters.

However, it has become increasingly clear that simply controlling industrial pollution is not enough to restore and protect Michigan waterways and the Great Lakes. The progress achieved in the last 15 years has stalled, and some positive trends have reversed. As stated in *The Great Lakes Green Book:* "We are going in the wrong direction."[1]

Irresponsible land use is now one of the most important threats facing the Great Lakes and inland waterways. Sprawling development and highway expansion create contaminated runoff. The pace and intensity of development increases the volume of water running through municipal systems. Impervious surfaces prevent the soil from absorbing waste accumulated in stormwater, and instead serve as a swift conduit to transmit that waste into the Lakes and connected waterways. In addition to causing direct runoff into the Lakes, these practices strain the capacity of municipal water treatment, resulting in sewage overflows, drinking water contamination and beach closings. Moreover, development is overtaking wetlands and other crucial habitats.

In contrast to industrial pollution, land use does not have defined discharge points that can be easily identified and regulated. To restore and protect the Great Lakes, Michigan needs to restore and protect the health of inland waterways. Since the source of the pollution is diffuse, the response must be distributed as well.

More than 70 organizations representing millions of residents in the region have joined a new coalition to restore and protect the Great Lakes. The Healing Our Waters-Great Lakes Coalition seeks to secure a sustainable restoration plan—including a plan to stop stormwater pollution—and the billions of dollars of state and federal funding needed to implement it.

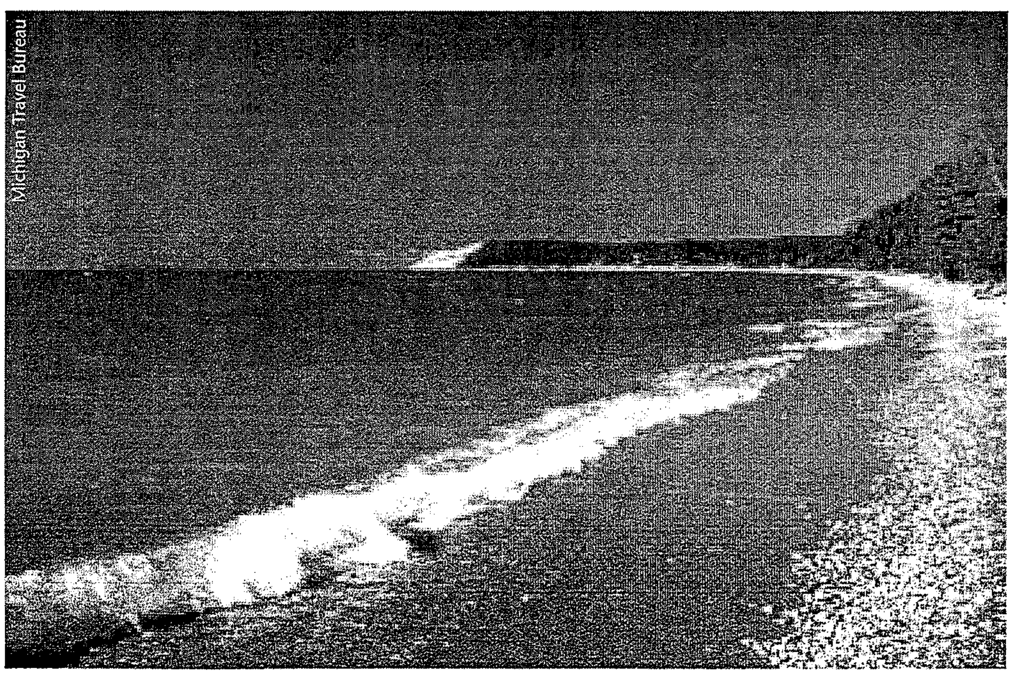
The coalition is currently working to develop a consensus Great Lakes restoration plan through the Great Lakes Regional Collaboration, led by the U.S. Environmental Protection Agency. The draft *Action Plan to Restore and Protect the Great Lakes* released in July 2005 calls for nearly $14 billion in new funding to help municipalities across the region plan and implement effective stormwater programs, with emphasis on comprehensive stormwater management, including low-impact development and other "soft-path" controls. The plan also sets a goal of virtually eliminating sewage overflows, primarily caused by stormwater infiltration of sewage systems, by 2020.

Implementing the plan will require action by Congress and the Great Lakes states. However, if done right, local governments will be doing most of the real work to stop runoff pollution—making individual development decisions, promoting smart growth patterns and encouraging innovative measures to prevent contaminated runoff at the source. Innovative low-impact development techniques can allow a community to grow while reducing the impact of development on inland water resources. They can also restore natural functions to existing urban areas and encourage revitalization, reducing pollution.

This report documents where development is occurring in Michigan and identifies areas of the state vulnerable to water quality decline. It also suggests policy ideas for local government to use in protecting water resources from new development or in restoring impaired waterways in urban areas. Taking advantage of these policies, local government in Michigan can play a central role in restoring and protecting local water resources and the Great Lakes.

For More Information

For more information on the Healing Our Waters-Great Lakes Coalition, visit www.restorethelakes.org.



Lake Michigan from Empire, MI.

Sprawling Development Is Polluting Michigan's Water

Despite progress in controlling industrial water pollution over the last 30 years, water quality problems in Michigan persist. Most urban and suburban watersheds, and the near-shore areas of Great Lake cities, still do not have water that:[2]

- is safe for swimming;
- contains fish that are safe to eat; or
- supports diverse communities of plants and wildlife.

The Michigan Department of Environmental Quality (DEQ) monitors the status of lakes and rivers across the state. In the latest water quality report, the DEQ found that:[3]

- 80 miles of Michigan's Great Lakes shoreline is too polluted for use as a public water supply.
- More than a quarter of Michigan's inland lakes have high nutrient levels, which contribute to algae blooms, low oxygen levels and poor conditions for wildlife.
- At least 25 percent of the stream miles in Michigan tested between 1997 and 2003 did not fully support wildlife, swimming, drinking or fish consumption.
- Many impaired waterways are located in the southern half of the Lower Peninsula, near the majority of Michigan's population.

Irresponsible land use is one of the primary factors behind water pollution.[4] In particular, paving land increases the amount of runoff after rainstorms and seeds the runoff with contamination.

After heavy rainfall, water flows down rooftops, sidewalks, parking lots and streets, carrying everything from sediment to pesticides into waterways. In some areas, runoff overwhelms outdated sewage infrastructure, spilling raw or partially-treated sewage into waterways.

As a result, Michigan's streams, rivers and lakes become less suitable for drinking and less able to support a diverse community of wildlife. Areas downstream become more prone to flooding and sewage overflows. And the pollution ends up in the Great Lakes.

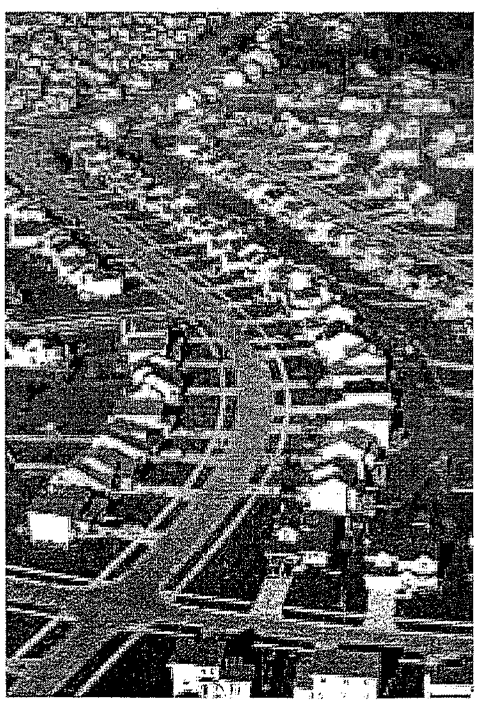
Development Is Increasing Faster Than Population Growth

Michigan is developing in ways that aggravate water quality problems. Between 1982 and 1997, developed land in the state increased by more than 30 percent.[5] New homes, shopping centers and businesses continued to move away from city centers into once-rural areas.

Land use grew much faster than population across much of the state. In some places, such as the Detroit and Saginaw metro areas, land use increased more than ten times faster than population.[6]

The trend toward this type of sprawling growth is readily apparent in Southeast Michigan:[7]

- Between 1990 and 2000, developed land increased by 17 percent, while population only increased by 5 percent.
- Almost half of the growth in land use was due to decreasing density of new residential areas.



- People leaving urban Detroit for the suburbs aggravated the trend. During the decade, over 7 square miles of land in urban Detroit became vacant.
- Most of the land available for future development is in outlying parts of the region, where plans and zoning specify low-density development typified by larger homes on larger lots.

This type of growth increases dependence on the automobile and requires more roads and paved land to serve a smaller number of people. Paving natural areas can have serious consequences for water quality, both locally and in areas downstream.

Development Causes Contaminated Runoff

Paving land with hard surfaces causes increased levels of stormwater runoff, which carries pollutants from roads, rooftops and parking lots into creeks and rivers.

When rain falls on natural, undeveloped land, water is captured by leaves, branches, ground cover, roots or soil. At Michigan's latitude and with its climate, much of the rain eventually evaporates back into the air. The remaining water either flows into a stream or filters underground into the water table.[8] In the process, vegetation and soils filter and clean the water of sediment and pollution.[9]

However, when natural landscape is replaced with a road, a driveway or a building, the ground becomes less able to capture water. Concrete, asphalt and rooftops do not absorb water. Instead, these impervious surfaces create runoff, directing large volumes of rainfall into gutters, trenches, canals and storm sewers.

High volumes of this runoff quickly reach nearby creeks, rivers and lakes:[10]

- Replacing a meadow with a parking lot increases runoff by about 16 times.[11]

- In developed areas, up to 50 percent of rainwater or snowmelt becomes surface runoff.[12]
- In downtown areas, 90 percent or more of precipitation becomes runoff.[13]

This effect is apparent in Michigan:

- From 1964 to 1995, development-caused runoff in the Rouge River watershed increased the frequency of peak flooding levels by four times.[14] Development caused more water to flow immediately downstream as opposed to evaporate or filter into the water table.
- Sprawling development in the Detroit metro area built between 1982 and 1997 diverts over 8 billion gallons of water from the underground water table annually.[15]

Patricial Pennell, www.raingardens.org

Runoff from paved areas can carry pollutants (like the oil in this parking lot) into rivers.

Runoff Pollutes Drinking Water and Degrades Wildlife Habitat

Pollution from runoff causes significant problems for communities across the state. Contaminated drinking water must be filtered and treated before public use—which is harder and more expensive to do with more polluted water. Runoff also damages wildlife habitat and makes waterways less suitable for recreation.

Polluting Drinking Water

A source of clean drinking water is one of the most important requirements for a healthy community. Natural areas filter pollutants out of runoff and keep drinking water sources clean, making them a valuable part of the natural infrastructure that supports communities across the state.[16] Because natural areas provide clean water for free, their value often goes unrecognized and unincorporated into planning decisions.

In Michigan, public water supply systems use over 1.2 billion gallons of water per day. Close to 80 percent of that water comes from surface sources, including the Great Lakes and nearby rivers.[17] When this water is not clean, public water supply agencies have to spend money building and operating water treatment plants to remove contaminants, or risk making people sick.[18]

Runoff can make water supplies more polluted and increase water treatment costs for local governments. For example, New York City estimated that expanded development in the Catskill Mountains would pollute the city's water supply reservoirs, requiring up to $8 billion for a new treatment plant. The city determined that preserving natural areas to protect the reservoirs would ensure clean water for $5 billion to $7 billion less.[19]

Runoff can contain a variety of harmful contaminants that impair drinking water quality and threaten public health, including fallen air pollution, pesticides, and pollution from roads, like oil, salt, sediment and bits of rubber. Some of these chemicals are toxic, such as lawn care pesticides and diesel exhaust particles that fall back to the ground.

Other contaminants can become toxic during the drinking water treatment process. Drinking water treatment plants often use chlorine to kill the bacteria in the water before pumping it into homes and businesses. While this step protects the public from bacterial infections, chlorine treatment can produce byproducts when it reacts with organic pollutants and sediments that are also in the water. These chlorinated byproducts, such as trihalomethanes and haloacetic acids, are suspected to cause birth defects, miscarriages, and cancer.[20] Chlorination tends to be the treatment of choice in the Great Lakes region.[21]

Degrading Wildlife Habitat

Runoff can also reduce the ability of a waterway to support a full, diverse and healthy range of wildlife—reducing the capacity of the ecosystem to absorb and filter pollution, or to support activities like recreational fishing.

Runoff comes in large amounts after rainstorms, eroding stream channels and destabilizing stream banks, increasing the amount of sediment in the water.[22] These changes disrupt habitat for aquatic organisms and pollute the water.

Runoff also carries nutrients like phosphorus and nitrate compounds. These chemicals promote excessive growth of harmful aquatic vegetation like algae. As this vegetation dies and decays, it removes oxygen from the water, which can kill local species of aquatic plants and fish. This process is known as eutrophication, and it makes waterways less able to support fishing, recreation, industry and drinking.[23]

Increased pollution and degraded habitat kill sensitive species and lead to a shift toward more pollution-tolerant insects and weeds. Waterways surrounded by urban areas and with high levels of treated sewage discharge tend to have an impaired aquatic community, with a narrow range of pollution-tolerant species.[24] Waterways fed by land with a large amount of forest and wetlands are more likely to have a full and healthy aquatic community. Forests and wetlands provide a buffer from runoff pollution and help to maintain a healthy supply of water, food and habitat for sensitive species.[25]

Runoff Causes Flooding and Sewer Overflows

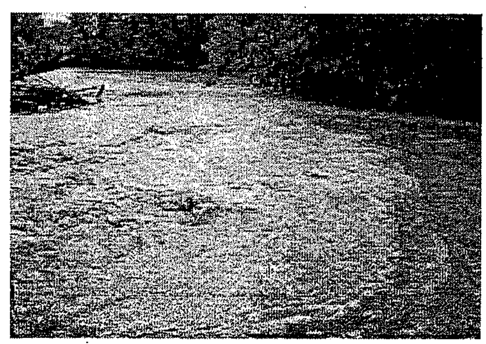
Runoff causes flooding in downstream areas by increasing the levels of water in a stream immediately after a storm. In some areas, flooding overwhelms outdated sewage infrastructure, spilling raw or partially-treated sewage into rivers and the Great Lakes.

Increasing Flooding

Runoff increases the amount of water reaching a waterway after a storm and raises the elevation of the flood plain, leading to higher flood vulnerability in downstream areas.

With 30 to 60 days of thunderstorms per year, Michigan can experience serious flooding.[26]

- Approximately six percent of Michigan's land is flood-prone, threatening about 200,000 buildings.[27]
- Flooding is the leading cause of disaster declarations by the governor or the president.[28]



www.raingardens.org

Runoff carrying sediment and pollution into Emmons Creek, in Caledonia, MI.

- Michigan's annual flood-related damages are estimated to be between $60 and $100 million.[29]
- After flooding in May 2004, almost 34,000 people filed disaster claims with the Federal Emergency Management Agency, requesting more than $50 million in assistance.[30]

The experience of New Brunswick, New Jersey illustrates the connection between increased runoff and intensified flood damage. After Hurricane Floyd dropped 11 inches of rain on the New Brunswick area in 1999, the Raritan River escaped its banks and inundated part of the city, causing extensive damage. Upstream, development had added more than 2,700 acres of impervious surface (an 18.8% increase) in the previous 15 years.[31] The extra water diverted into the Raritan River by runoff from this development undoubtedly made the flooding damage in New Brunswick more extensive.

Sewage Overflows

Some storm drains are combined with sewage systems, which deliver contaminated water to a treatment plant. After heavy rainfall, these systems can overflow, dumping raw or partially-treated sewage into waterways. The U.S. EPA estimates that every year, trillions of gallons of untreated human sewage are discharged from such overflows.

In 2004, stormwater runoff led to the discharge of more than 27 billion gallons of sewage into Michigan waterways, and ultimately to the Great Lakes.[32]

Sewage discharge can contaminate waterways with fecal bacteria from human waste, making rivers and lakes unsafe for swimming or drinking.[33] In 2004, Michigan officials closed a swimming beach or issued a bacterial contamination advisory for a total of 255 days (by county).[34]

A stormwater outfall discharging directly into a waterway.

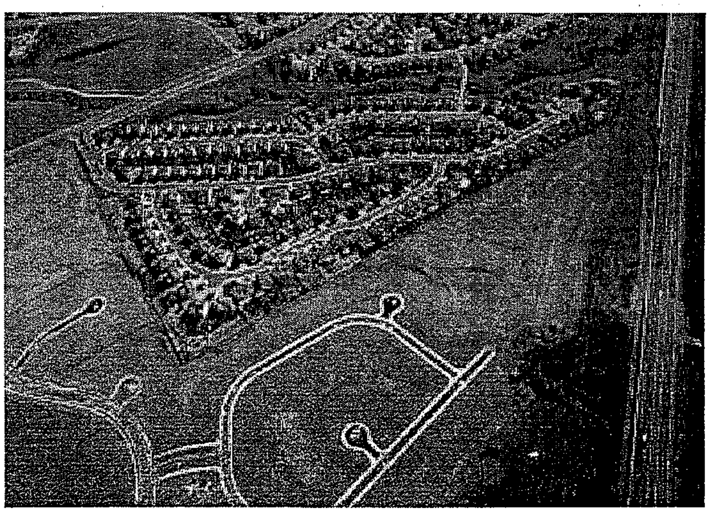
For Additional Information

For further background on the causes and effects of stormwater pollution, see:

- *Urbanization Impacts on Aquatic Resources*, Public Sector Consultants for the Michigan Land Use Leadership Council. Available at www.michiganlanduse.org/resources/councilresources.htm
- *Stormwater Strategies: Community Responses to Runoff Pollution*, Natural Resources Defense Council. Available at www.nrdc.org/water/pollution/storm/stoinx.asp
- *Site Planning for Urban Stream Protection, Chapter 2: The Importance of Imperviousness*, The Center for Watershed Protection. Available at www.cwp.org/SPSP/TOC.htm

Michigan Watersheds at Risk from Contaminated Runoff

Watersheds in Michigan with intermediate levels of impervious surface cover and high levels of growth are at risk of developing water quality problems caused by runoff from new development. As future development expands into these areas, more contaminated runoff is likely to enter local waterways and flow downstream to the Great Lakes.



Development near rivers harms water quality.

Impervious Surface and Watershed Health

The amount and location of impervious surface in watersheds is closely connected to the health of downstream waterways.

- Pollution problems grow as urbanization increases, as forest cover decreases, and as riparian buffers between development and waterways decrease.[35]
- Watersheds with a large amount of forested cover, a large riparian buffer, and low levels of impervious surface tend to have better water quality. When a watershed is developed to the point where 25 percent or more of the land is impervious, severe water quality degradation results.[36]
- Water quality problems tend to become apparent when 5 to 10 percent of a watershed is covered with impervious surfaces. Adding more impervious surface leads to more serious water quality problems.[37]

A significant number of watersheds in Michigan are vulnerable to development-

Figure 1: Impervious Cover in Michigan Watersheds

Impacted
(>15 Percent impervious)

Moderately Impacted
(Between 10 and 15 percent impervious)

Vulnerable
(Between 5 and 10 percent impervious)]

caused runoff and water quality problems. Based on analysis of 2001 land use data obtained from the Michigan Department of Environmental Quality, areas in the urban cores of major cities in Southern Michigan have the highest levels of impervious surface. Watersheds surrounding these areas have intermediate levels of impervious surface coverage and still retain significant natural areas that mitigate water pollution. (See Methodology for analysis description.)

As shown in Figure 1, of Michigan's roughly 1,650 sub-watersheds:

- 15 percent have between 5 and 10 percent impervious cover and are vulnerable to developing significant water quality problems with increased development.
- Another 4 percent have between 10 and 15 percent impervious cover and are moderately impacted.
- 5 percent have more than 15 percent impervious surface and are impacted.

Watersheds in heavily urbanized areas tend to have the most severe water quality problems in the state. Some watersheds in central Detroit have up to 40 percent of their land area covered by impervious surface. Waterways in these areas receive heavy loads of pollution from stormwater runoff, in addition to industrial discharge and sewage treatment plant discharge.

Vulnerable watersheds tend to be in the same locations that are under increasing pressure from development—the outlying areas of major population centers.

In 2001, the Michigan Land Resource Project, an initiative of the Frey Foundation and the W.K. Kellogg Foundation on behalf of the Michigan Economic and Environmental Roundtable, projected what the state would look like in 40 years if business as usual continued. They concluded that Michigan would add over 4 million acres (6,250 square miles) of new development by 2040, nearly tripling the amount of built land.[38]

In Southeast Michigan, local governments forecast a 36 percent increase in developed land from 2000 to 2030. The addition of a half-million more people (a 12 percent increase in population), coupled with more households and land zoned for low-density development, could drive land use to increase at least as fast as recent trends.[39]

If recent development patterns continue, in addition to growing amounts of built land, many more Michigan waterways will succumb to the effects of stormwater runoff pollution.

Rapidly Growing Municipalities

Southeast Michigan is the center of development activity in the state, followed by Southwestern Michigan near Grand Rapids.

Nearly 23,000 permits for single-family residences—a proxy measure for residential development characteristic of "sprawl"—were issued in Southeast Michigan in 2004, 55 percent of all such permits issued in the state. Over 5,500 permits were issued in the area surrounding Grand Rapids, accounting for 15 percent of the statewide total.

Figure 2 shows the number of building permits issued by municipality or unincorporated county across the Lower Peninsula.

Figure 3 shows the municipalities that issued more than 200 building permits in 2004, plus counties that issued over 500 building permits in unincorporated areas. These areas make up the 43 most rapidly developing municipalities in the state.

Figure 2: Building Permits Issued for Single-Family Residences in 2004

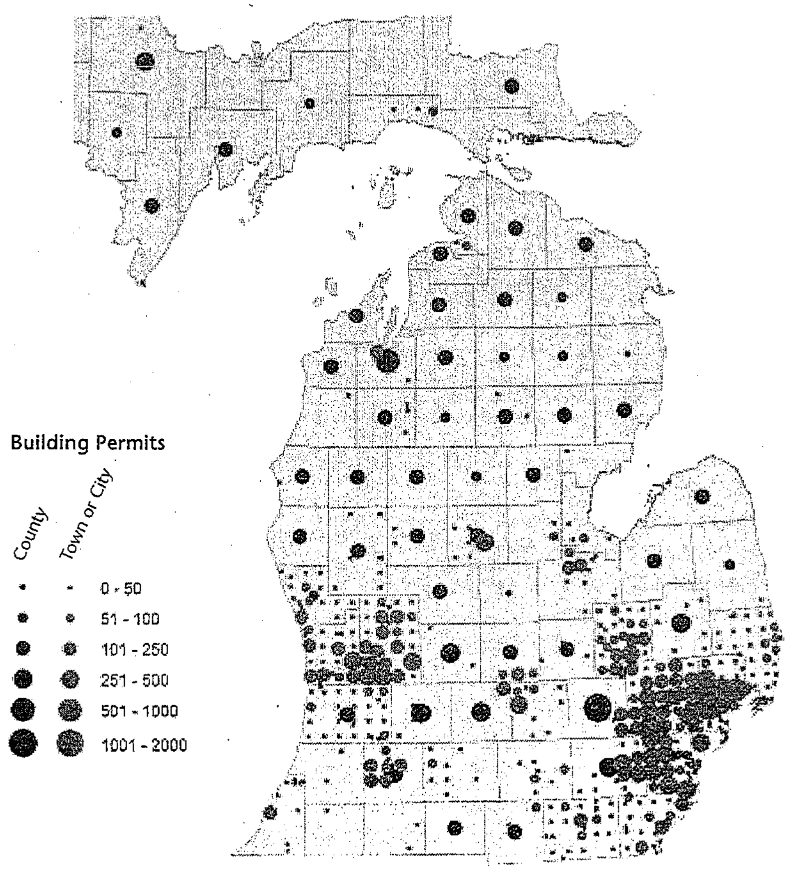


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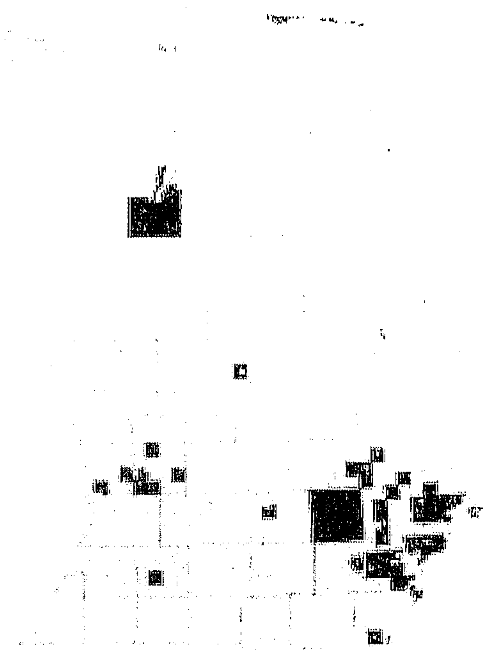
Figure 3: The Most Rapidly Developing Municipalities and Counties in Michigan



Watersheds in Areas of Rapid Growth Are Most at Risk

Watersheds in rapidly developing communities are most at risk for water quality degradation caused by runoff from new development. We define the most at-risk communities as areas that issued more than 200 building permits for single family homes in 2004 and occupy watersheds vulnerable to water quality decline (between 5 and 15 percent impervious surface).

These areas are primarily surrounding Detroit and Grand Rapids, with other important areas near Kalamazoo, Lansing and Traverse City, including:

- **Southwest Detroit Metro Area:** Ann Arbor, Ypsilanti, Superior, Canton, Van Buren, Romulus, Huron, Brownstown and Bedford;
- **Northwest Detroit Metro Area:** Clinton, Sterling Heights, Troy, Chesterfield, Macomb, Shelby, Rochester Hills, Washington, Oxford, Independence, White Lake, Commerce, Novi, Northville, Davison, Grand Blanc, Holly, Mundy, Brighton and unincorporated Livingston County;
- **Grand Rapids Area:** Lowell, Plainfield, Gaines, Byron, Wyoming, Georgetown and Holland;
- **Additional Areas:** Portage, Delhi and Union, and Grand Traverse County.

These areas are shown in Figure 4. Table 1 lists the number of building permits in each area in 2004. Figure 5 shows a close-up view of vulnerable watersheds and rapidly developing communities in Southeast Michigan.

Figure 4: Communities Most at Risk of Water Quality Degradation Caused by Runoff from New Development

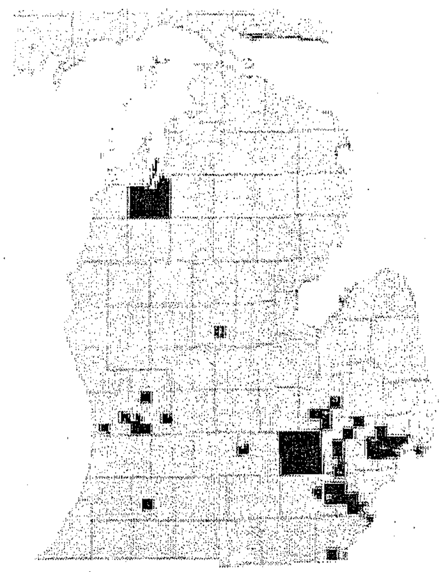


Figure 5: Rapidly Developing Towns and Vulnerable Watersheds in Southeast Michigan

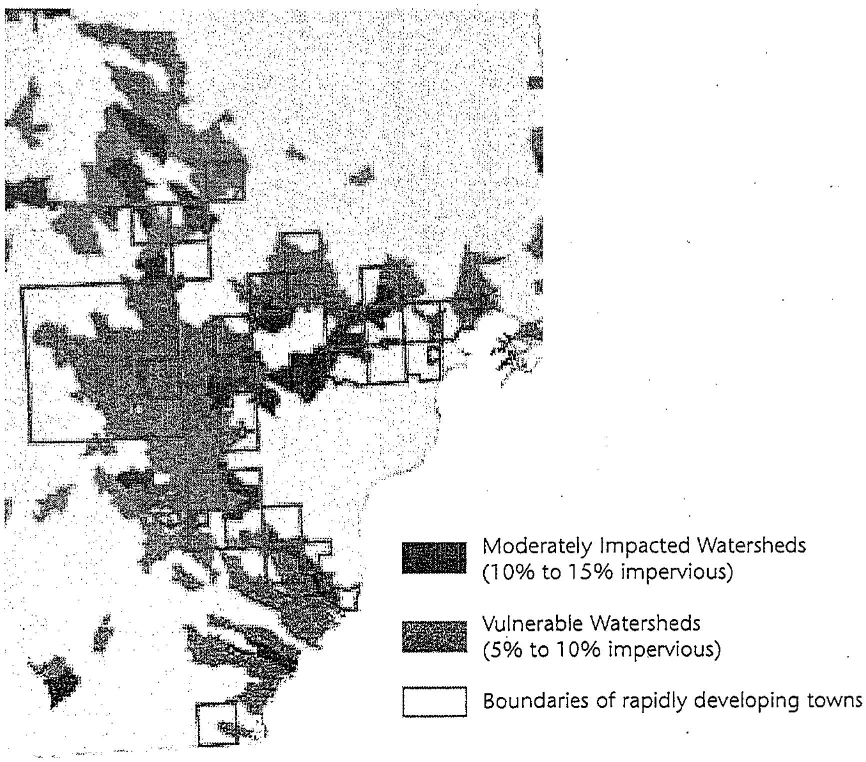


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Table 1: Number of Single-Family Home Building Permits Issued in 2004 in At-Risk Municipalities

	Town	County	Permits Issued for Single-Family Homes in 2004
1	Livingston County	(Unincorporated)	1,563
2	Macomb Township	Macomb	1,087
3	Shelby Township	Macomb	755
4	Chesterfield Township	Macomb	663
5	Sterling Heights	Macomb	621
6	Grand Traverse County	(Unincorporated)	581
7	Novi	Oakland	505
8	Ypsilanti Township	Washtenaw	495
9	Northville Township	Wayne	488
10	Van Buren Township	Wayne	469
11	Huron Township	Wayne	465
12	Lowell Township	Kent	399
13	Canton Township	Wayne	396
14	Washington Township	Macomb	369
15	Georgetown Township	Ottawa	353
16	Brownstown Township	Wayne	343
17	White Lake Township	Oakland	339
18	Union Township	Isabella	328
19	Commerce Township	Oakland	326
20	Grand Blanc Township	Genesee	316
21	Byron Township	Kent	314
22	Troy	Oakland	311
23	Rochester Hills	Oakland	302
24	Ann Arbor	Washtenaw	283
25	Delhi Township	Ingham	266
26	Gaines Township	Kent	252
27	Independence Township	Oakland	246
28	Romulus	Wayne	245
29	Mundy Township	Genesee	244
30	Oxford Township	Oakland	242
31	Bedford Township	Monroe	241
32	Holly Township	Oakland	236
33	Brighton Township	Livingston	227
34	Clinton Township	Macomb	219
35	Wyoming	Kent	217
36	Plainfield Township	Kent	214
37	Superior Township	Washtenaw	211
38	Portage	Kalamazoo	209
39	Davison Township	Genesee	207
40	Holland Township	Ottawa	201

Low-Impact Development and Smart Growth Can Prevent Water Pollution

Irresponsible land use creates contaminated runoff at two separate levels. At the level of the individual development, traditional stormwater management practices treat stormwater runoff as a waste product, creating more runoff at a given site by using gutters and drains to dispose of runoff in ponds, creeks and sewers. These practices at best fail to take advantage of natural features of the landscape that could minimize pollution—and at worst, reduce the ability of the landscape to filter pollution out of the water.

At the aggregate, community-wide level, sprawling growth patterns create larger amounts of runoff for a given number of residents and can encroach into critical areas of the ecosystem. For example, a community of low-density development with a large network of roadways along a river will impact a larger area and cause greater amounts of runoff than a high-density, low-impact development, while disrupting the natural water cleaning ability of the land around the waterway. Together, sprawling development and traditional stormwater management pollute waterways.

Two approaches are necessary to solve the problem—low impact development and smart growth. At the site level, low-impact development techniques aim to make the built environment function more like the natural environment. By customizing the approach to natural features of the landscape, incorporating green spaces, planting native landscaping, using absorbent surfaces, and implementing other simple, cost-effective and low-tech methods, low-impact development manages stormwater close to where it falls. Low-impact practices capture and treat stormwater on-site, allowing runoff to soak into the ground, evaporate or be stored for later use in irrigation.

At the community-wide level, smart growth practices reduce the area of impact and protect critical parts of the ecosystem. Smart growth uses strategic open spaces, infill development, town center redevelopment and clustered, higher-density design to minimize runoff in the aggregate.

Combining these two approaches in a comprehensive plan to manage growth will magnify the benefit of individual policies and lead to cleaner water locally and in the Great Lakes. There are a variety of additional benefits as well, including more beautiful and desirable urban areas; reduced costs for municipalities; increased developer profits and improved quality of life.

Principles of Low-Impact Development

Underlying low-impact development is a set of principles that focus on creating a built landscape with the function of a natural landscape—or retrofitting an urban area to restore ecological function. Low-impact principles include:[40]

1) Focus on prevention of runoff rather than mitigation;
2) Conserve natural landscape features and processes to retain stormwater and filter pollution;
3) Emphasize simple, non-structural, low-tech and low-cost methods;
4) Manage runoff as close to the source as possible;
5) Minimize effective impervious surface area by directing runoff to "rain gardens" and other natural infrastructure;
6) Encourage private landowner stewardship to reduce stormwater runoff;
7) Take a "fix-it-first" approach to public infrastructure, prioritizing the updating and separating of stormwater and sewer systems; and
8) Customize the approach to the land under consideration.


www.raingardens.org

A "rain garden" designed to absorb and treat runoff from a parking lot.


Alabama State Water Program

Permeable pavement.

For Additional Information

For more information on low-impact development, see:

- *Catching the Rain: A Great Lakes Resource Guide for Natural Stormwater Management,* American Rivers. Available at www.americanrivers.org.
- "Low-Impact Development," Chapter 12 of *Stormwater Strategies: Community Responses to Runoff Pollution.* Natural Resources Defense Council. Available at www.nrdc.org.
- *Low-impact Development: Urban Design Tools,* a web page addressed to watershed managers, created by the U.S. EPA and the Low-Impact Development Center. Available at www.lid-stormwater.net
- *Low-Impact Development Design Strategies: An Integrated Design Approach,* Prince George's County, Maryland and U.S. EPA. Available at www.epa.gov/owow/nps/lid.
- The Green Roof Research Program at Michigan State University: www.hrt.msu.edu/greenroof.

Principles of Smart Growth

Low-impact development principles work equally well in a variety of situations—from urban retrofits to new sprawl-style developments in rural areas. Thus, a broader approach to creating sustainable communities is also necessary to maximize the impact of low-impact development.

Low-density developments tend to have large amounts of impervious surface serving a smaller number of people. As a result, communities zoned for low-density development impact a much larger area. According to research at the U.S. EPA, low-density development (1 unit per acre and 20 percent impervious cover) creates almost three times as much runoff as high-density development (8 units per acre and 65 percent impervious cover).[41]

Several additional studies document the benefits of higher-density development in reducing runoff:

- Researchers in Connecticut found that low-density sites produce 95 percent more runoff during construction than high-density sites.[42]
- The Chesapeake Bay Foundation found that high density developments convert 75 percent less land area, create 42 percent less impervious surface and produce 41 percent less runoff than low-density development.[43]
- The New Jersey *State Plan* calls for higher-density development around town centers and infill development in areas with existing infrastructure. Researchers at Rutgers University found that this plan would reduce runoff by 30 percent versus business as usual.[44]

Accordingly, low-impact development techniques should be used in conjunction with a broader approach to creating healthy, sustainable communities following the principles of smart growth. Ideally, a smart growth community will:[45]

- Mix land uses;
- Use compact building and community design, built around vital town centers;
- Create a range of housing opportunities;
- Create walkable neighborhoods;
- Foster distinctive, attractive communities;
- Preserve open space, farmland, natural beauty and critical environmental areas;
- Invest in and maintain existing communities;
- Restore and redevelop abandoned buildings and sites;
- Provide a variety of transportation choices;
- Make development decisions predictable, fair and cost-effective;
- Encourage community involvement in planning and development decisions; and
- Coordinate planning across town and regional boundaries.

For Additional Information

For additional detail on the core principles of smart growth, a brief history of the issue, and a detailed list of policies associated with smart growth, please see the American Planning Association's *Policy Guide on Smart Growth*, available at www.planning.org.[46] See also *Smart Growth for Clean Water: Innovative Strategies for NPDES Phase II Stormwater Management in Michigan*, a report by the Michigan Environmental Council, available at www.mecprotects.org.

Local Governments Should Promote Low-Impact Development and Smart Growth

Local governments are the center of land-use decision-making in Michigan. Villages, townships, cities and counties all play a role in how development proceeds within their boundaries.

Local governments regulate development using two main tools: master growth plans and zoning ordinances. The master planning process represents a long-term vision for how, where and when growth is intended to occur—and what natural features or resources deserve preservation. Zoning ordinances are the nuts and bolts of the master plan, identifying areas where residential, commercial or industrial development is allowed and setting rules for design and construction. Both of these forums offer opportunities to protect water quality by promoting low-impact development and smart growth.

A comprehensive approach to policy reform will have the greatest effect, combining the best features of on-site low-impact development techniques and community-wide smart growth strategy.

Policies that will protect waterways from new sources of stormwater runoff include establishing buffer zones around waterways (in both the master plan and the zoning ordinance) and legally establishing a no net runoff standard as a part of the zoning code. In addition, communities in more heavily urbanized areas can set up retrofit programs to mitigate the effects of pre-existing development. These changes need to be coupled with broader smart growth strategies, including incentives for clustered development around town-centers, infill development and redevelopment, strategic open land preservation and coordinated planning across local and regional boundaries.

For Additional Information

For a guide to local government and land use planning in Michigan, see:

- Citizen's Guide to Land Use Planning, *Huron River Watershed Council, available at www.hrwc.org/program/land.htm.*
- Better Site Design: A Handbook for Changing Development Rules in Your Community, *Center for Watershed Protection. Available for purchase, with associated free resources available at: www.cwp.org/bfb_better_site_design.htm*

Creating Buffer Zones Around Waterways

Waterways with healthy riparian areas are much less vulnerable to runoff pollution. Preserving these areas is an important way local governments can prevent water quality problems, while also offering beautiful natural areas for citizens to enjoy.

Community master plans should identify riparian areas as a critical natural resource and source of clean drinking water. Accordingly, the plan should establish the intent of preserving a natural buffer zone along and around waterways. The state of New Jersey uses a 150 to 300-foot buffer to protect creeks, streams, rivers, reservoirs and headwaters that are important sources of drinking water or have other important values.[47]

However, master planning documents are not legally binding—rather, they indicate the vision for how the community will grow and develop over time. To legally require preservation of a buffer zone around a waterway within a locality, a buffer zone ordinance would be required. The ordinance would establish specific rules for the establishment, protection and maintenance of riparian areas along stream corridors.

A model buffer zone ordinance establishing a 200 foot buffer can be found at the Center for Watershed Protection's Stormwater Manager's Resource Center, online at www.stormwatercenter.net. Additional information about stream buffer design can be found in *The Architecture of Urban Stream Buffers*, a publication of the Center for Watershed Protection available at www.cwp.org.

Establishing a "No Net Runoff" Standard for New Development in Areas Outside the Urban Core

A community zoning ordinance establishes rules that govern the design and construction of all types of development, from residential areas to commercial shopping areas and office complexes to industrial sites.

Zoning regulations offer an opportunity to require new development to prevent stormwater runoff. The key features of a low-impact stormwater ordinance should include:

1) A standard of no net runoff from new development. An appropriate standard would be replication of pre-development runoff characteristics during a 2-year, 24-hour storm event. This level of performance would offer significant benefits in terms of detaining runoff and treating runoff contamination. In addition, research has shown that this level of performance protects downstream areas from flooding even during a 100-year storm.[48]

2) Flexibility for developers to use a wide range of non-structural low-impact development practices to achieve that standard.

3) Revision of outdated requirements that interfere with low-impact development practices or promote greater levels of impervious surface, including requirements for excessively wide streets, large setbacks or traditional stormwater infrastructure.

The zoning ordinance should specifically endorse and encourage low-impact

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development features that residents and local leaders find desirable, while revising older parts of the ordinance that prohibit effective stormwater management. For example, the town of Lacey in Washington State has adopted rules eliminating legal barriers to the use of zero-impact principles. The goal of the ordinance is to allow developments to achieve near-zero effective impervious surface. However, the ordinance is voluntary and no incentives or requirements to use low-impact techniques yet exist. To date, two separate developmers have taken advantage of the ordinance. The Villages at Hicks Lake and the Long Lake Retirement Community plan to incorporate a range of low impact techniques to achieve zero impact, including narrower roads, forest conservation, bioretention swales and permeable pavement.[49]

In 1996, the Center for Watershed Protection gathered experts together in a site-planning roundtable and produced a list of 22 model development principles.[50] These principles, plus a codes and ordinances worksheet, can help community groups evaluate local zoning policy and identify areas where changes to reduce impervious cover, conserve natural features and prevent stormwater pollution are necessary.

For Additional Information

For further information on model development principles, see:

- *Site Planning Model Development Principles*, Center for Watershed Protection. Available at www.cwp.org/22_principles.htm.
- The "Codes and Ordinances" worksheet at the same site offers tools to evaluate your own community.
- A technical support manual with greater detail on each design principle and how to incorporate them into municipal code is available for purchase: *Better Site Design: A Handbook for Changing Development Rules in Your Community*, Center for Watershed Protection, www.cwp.org. Associated presentations and other free resources are available at www.cwp.org/bfb_better_site_design.htm.

Retrofit Programs in the Urban Core

Policies that reduce runoff from new development won't be as effective in more heavily urbanized areas of Michigan. Community organizations located in these areas can instead work with their local governments to establish retrofit programs to reduce the impact of existing development on water quality. Low-impact development principles are effective for retrofit projects as well as for new development.

For example, Chicago has established a requirement that all new or refurbished roofs in the city either use living material or a reflective surface. The intent of the rule is focused on the heat gain from so many black roofs and to promote energy efficiency. However, green roofs, such as the rooftop meadow atop Chicago City Hall, will also significantly reduce stormwater runoff.[51]

Seattle has established a retrofit program to address runoff from roadways called "SEA Streets." The program seeks to retrofit the ditch and culvert drainage system in the northern part of the city with innovative natural approaches to manage runoff. The first demonstration project included installation of vegetated swales, gardens, tree preservation and planting, and street improvements that reduce impervious surface cover.[52]

Local governments in Michigan should follow these examples and create their own retrofit programs. Low-impact development principles can help restore natural functions in these areas while improving natural beauty, energy efficiency, and quality of life.

Funding Retrofit Projects

Funding will likely be a major challenge facing any new retrofit project to improve urban stormwater infrastructure with low-impact techniques. The U.S. Environmental Protection Agency recommends the following resources to assist communities seeking funding for stormwater management:[53]

- **An Internet Guide to Financing Stormwater Management** - This site was designed to help communities find ways to fund stormwater management projects. http://stormwaterfinance.urbancenter.iupui.edu/
- **Catalog of Federal Funding Sources for Watershed Protection** - The Catalog of Federal Funding Sources for Watershed Protection Web site is a searchable database of financial assistance sources (grants, loans, cost-sharing) available to fund a variety of watershed protection projects. http://cfpub.epa.gov/fedfund/
- **State Revolving Fund** - State Revolving Fund programs in each state and Puerto Rico are funded by EPA and operated like banks. Assets are used to make low- or no-interest loans. www.epa.gov/owm/cwfinance/cwsrf/index.htm

In addition, if Congress and state governments act on the recommendations of the Great Lakes Regional Collaborative (see Introduction), new programs and funding sources will be created.

Promote Broader Smart Growth Strategies

Low-impact development reforms will be most effective when coupled with a broader strategy to create healthy, sustainable communities.

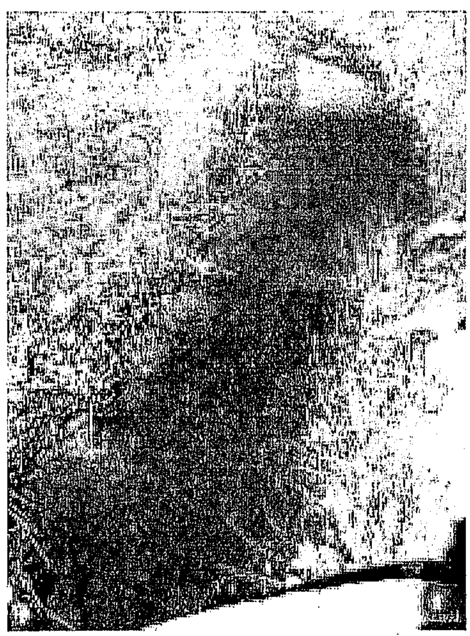
There are a variety of reasons to adopt a smart growth strategy to guide long-term development. In terms of water quality, smart growth reduces the overall potential for runoff. Smart growth has a variety of additional benefits, including:

- Cost savings for municipalities;
- Enhanced tourism and other business opportunities;
- Vital neighborhoods;
- Community quality of life;
- Recreation, parks and open space; and
- Improved transportation options.

Smart growth strategies have to be implemented at the local, county, regional and state level. Locally, governments can promote clustered development around town centers, infill development and redevelopment, and strategic open land preservation.

Because local governments can control their own growth decisions, but not those of neighboring areas, they should engage in coordinated planning across local and regional boundaries to create a plan for the future that is consistent across a wide area, and takes into account natural resources in a regional context. Local governments should also encourage leaders at the county and state level to facilitate the inclusion of smart growth principles in policies regulating growth and development.

Local governments in Michigan have the resources and tools to minimize the effect of development on water quality. By coupling low-impact development strategies with smart-growth principles in a comprehensive approach, communities can maximize the benefit of individual policies and create new patterns of land use. The rewards will include cleaner streams and rivers, fewer sewage spills, and healthier Great Lakes.



Low-impact development and smart growth techniques can prevent streams like Basset Creek (top) from turning into Whiskey Creek (bottom), and protect the Great Lakes from pollution.

Methodology

Impervious Surface Calculation

To calculate the levels of impervious surface in Michigan, we used two main data sources:

- 2001 land use data for Michigan's Lower Peninsula at 30 meters square resolution, obtained from the Michigan Geographic Data Library;[54] and
- U.S. Geological Survey watershed boundaries at the Hydrologic Unit Code-14 (HUC 14) level, obtained from the Michigan Geographic Data Library.[55]

After obtaining the data, we used Geographic Information Systems software to analyze land use and calculate the levels of impervious surface in each watershed.

1) Using ArcView GIS software, we cut the land use file into pieces representing each HUC 14 watershed in the Lower Peninsula.
2) We analyzed each individual watershed land-use file to determine the area of each type of land, listed in Table 2.
3) We calculated the percentage of the watershed covered by impervious surface, using the percentage of each land use type estimated to be impervious, as interpreted from work done by the Rouge Program Office to measure impervious surface coverage on various land uses in Southeast Michigan from aerial photographs, supplemented by similar studies of impervious cover from other locations.[56]

Identifying At-Risk Watersheds

To identify at-risk watersheds, we looked at municipalities that issued more than 200 building permits for single-family residences in 2004 (or unincorporated areas of counties that issued more than 500 building permits) that contained a watershed with more than 5 percent but less than 15 percent impervious surface.

Building permit information for 2004 was compiled by the U.S. Census bureau.[57] We linked permit data to a GIS file representing Michigan villages, townships, cities and counties to produce the building permit maps in the report and calculate overlap with specific watershed areas.

Table 2: Estimated Percentage Impervious Cover by Land Use

Land Use Code	Land Use Category	Percent Impervious Surface
0	Background	EXCLUDED
1	Low-Intensity Urban	19%
2	High-Intensity Urban	51%
3	Airports	53%
4	Roads and Parking Lots	53%
5	Non-Vegetated Farmland	2%
6	Row Crops	2%
7	Forage Crops	2%
9	Orchards	2%
10	Herbaceous Openland	2%
12	Low-Density Trees and Shrubs	2%
13	Golf Courses and Parks	11%
14	Northern Hardwood	2%
15	Oaks	2%
16	Aspens	2%
17	Other Upland Deciduous	2%
18	Mixed Upland Deciduous	2%
19	Pines	2%
20	Other Upland Conifers	2%
21	Mixed Upland Conifers	2%
22	Upland Mixed Forest	2%
23	Water	EXCLUDED
24	Lowland Deciduous Forest	2%
25	Lowland Coniferous Forest	2%
26	Lowland Mixed Forest	2%
27	Floating Aquatic	2%
28	Lowland Shrubs	2%
29	Emergent Wetland	2%
30	Mixed Non-Forest Wetland	2%
31	Sand and Soil	3%
32	Bare Rock	50%
33	Mud Flats	2%
35	Other Bare / Sparsely Vegetated	5%

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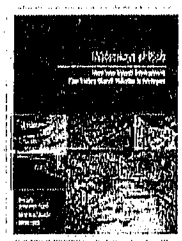
Reports



Waterways at Risk: How Low-Impact Development Can Reduce Runoff Pollution in Michigan

PIRGIM Education Fund

October 2005

Executive Summary | **News Release**

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Executive Summary

Many communities in Michigan are developing in ways that create water quality problems in the Great Lakes and inland waterways. Runoff from developed land contaminates waterways with pollution after rainstorms. Construction of roads and buildings replaces natural surfaces that store and clean rainwater with hard, impervious surfaces (like pavement) that divert water and pollution directly into creeks or into sewers. As a result, community growth can lead to higher levels of contaminated runoff, impaired drinking water quality, degraded wildlife habitat and uncontrolled sewage overflows.

One quarter of Michigan watersheds are impacted by or vulnerable to contaminated runoff from developed land.

• 5 percent of Michigan watersheds are impacted, with more than 15 percent of their land area covered by pavement and other impervious surfaces.

• Another 4 percent are moderately impacted, with between 10 and 15 percent impervious cover; and

• 15 percent of Michigan's watersheds are vulnerable to developing significant water quality problems as a result of expanded development, with between 5 and 10 percent impervious cover as of 2001.

• According to a 2001 forecast, Michigan will add over 4 million acres of new development by 2040, nearly tripling the amount of built land. Development on this scale threatens to pollute inland waterways and increase downstream impacts in the Great Lakes.

Watersheds in rapidly developing communities are most at risk, including areas surrounding Detroit and Grand Rapids, plus smaller areas near Kalamazoo, Lansing and Traverse City.

Municipalities that issued more than 200 building permits for single family homes in 2004 and occupy watersheds vulnerable to water quality decline include:

• **Southwest Detroit Metro Area:** Ann Arbor, Ypsilanti, Superior, Canton, Van Buren, Romulus, Huron, Brownstown and Bedford;

• **Northwest Detroit Metro Area:** Clinton, Sterling Heights, Troy, Chesterfield, Macomb, Shelby, Rochester Hills, Washington, Oxford, Independence, White Lake, Commerce, Novi, Northville, Davison, Grand Blanc, Holly, Mundy, Brighton and unincorporated Livingston County;

• **Grand Rapids Area:** Lowell, Plainfield, Gaines, Byron, Wyoming, Georgetown and Holland;

• **Additional Areas:** Portage, Delhi, Union, and Grand Traverse County.

Poorly designed development can cause water pollution, but development using innovative low-impact development and smart growth principles can greatly reduce runoff and prevent harm.

• Poorly designed developments treat stormwater runoff as a waste product, creating more runoff at a given site by using gutters and drains to dispose of runoff in ponds, creeks and sewers. The problem is aggravated by sprawling growth patterns that create larger amounts of runoff for a given number of residents. For example, a community of low-density development with a large network of roadways along a river will impact a larger area and cause greater amounts of runoff than a high-density, low-impact development, while disrupting the natural water cleaning ability of the land around the waterway.

• In contrast, low-impact development techniques replicate the natural functions of the environment on-site, using green spaces, native landscaping, and a variety of other simple, cost-effective and low-tech methods to capture and treat stormwater close to where it falls. In addition, smart growth practices reduce the area of impact and protect critical parts of the ecosystem by using strategic open spaces, infill development and redevelopment, and clustered, higherdensity design—minimizing runoff in the aggregate.

Local governments have the power to promote smart growth and low-impact development.

Local governments can protect and restore local waterways by establishing riparian buffer zones, requiring no net runoff from new developments and implementing smart growth strategies. These policies can be included in community master plans and stormwater management plans, and included as legal requirements in zoning ordinances.

Local governments should:

• Establish a natural buffer zone around creeks, streams or rivers. The state of New Jersey applies a 150- to 300-foot buffer zone to protect valuable drinking water supplies and their upstream headwaters.

• Change zoning policy in areas outside the urban core to require no net runoff from new developments. On-site measures should be capable of replicating pre-development runoff rates during a 2-year, 24-hour storm.

• Allow more flexibility in zoning policy to accommodate low-impact development principles. For example, zoning rules with strict requirements for wide streets or traditional stormwater infrastructure should be modified to allow equally effective low-impact strategies.

• Initiate low-impact retrofit programs in urban core areas like Detroit, Grand

Rapids, Flint, Saginaw and Lansing to mitigate the impact of existing development.

• Couple riparian buffers, "no net runoff" and retrofit policies with broader smart growth strategies, including incentives for clustered development around town centers, infill development and redevelopment, strategic open land preservation and coordinated planning across local and regional boundaries. A comprehensive approach to growth will magnify the benefit of individual policies—leading to cleaner water locally and in the Great Lakes.

PUBLIC INTEREST RESEARCH GROUP IN MICHIGAN
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Land Jurisdictions in Ventura County, California

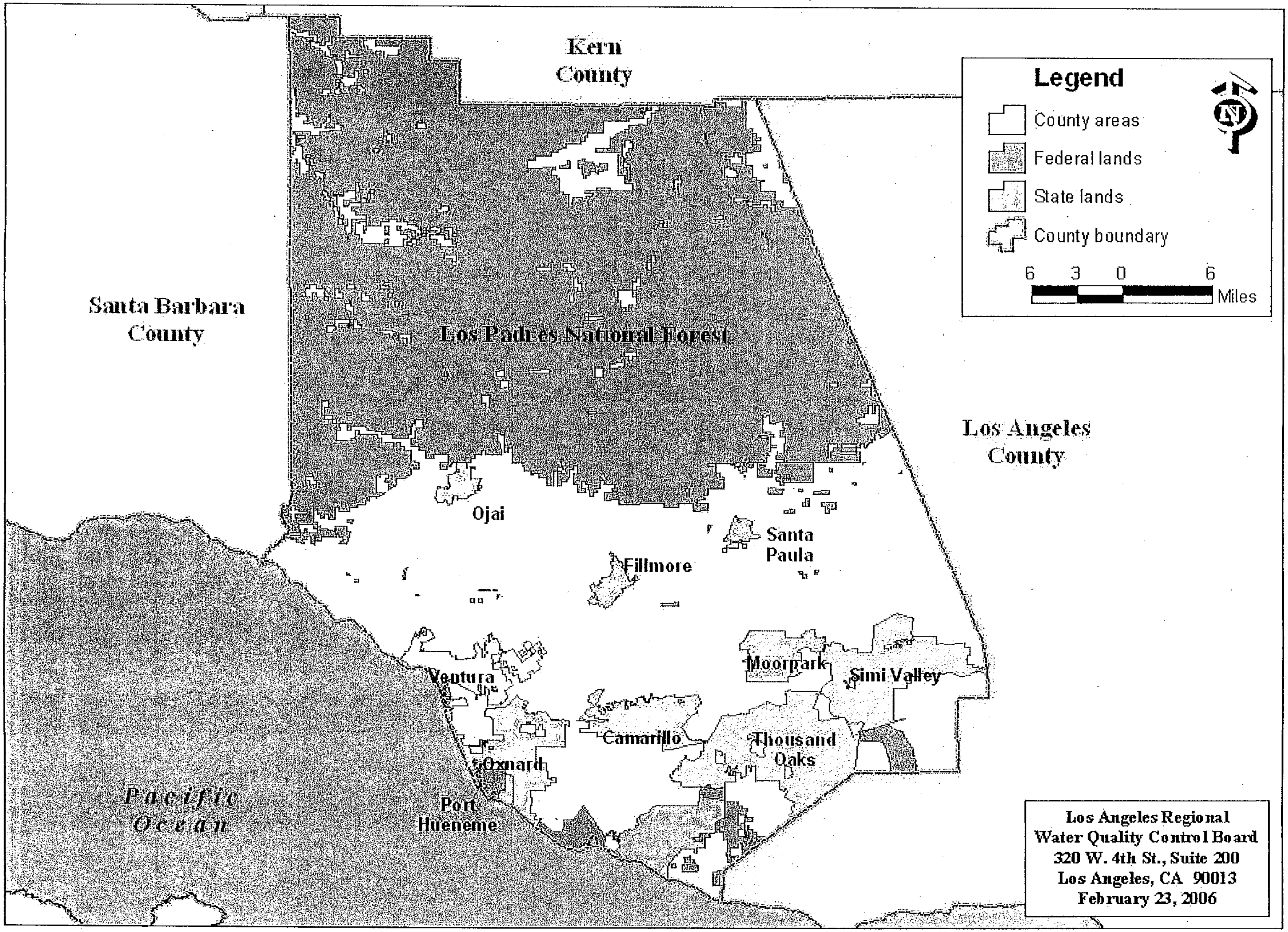

Figure 1

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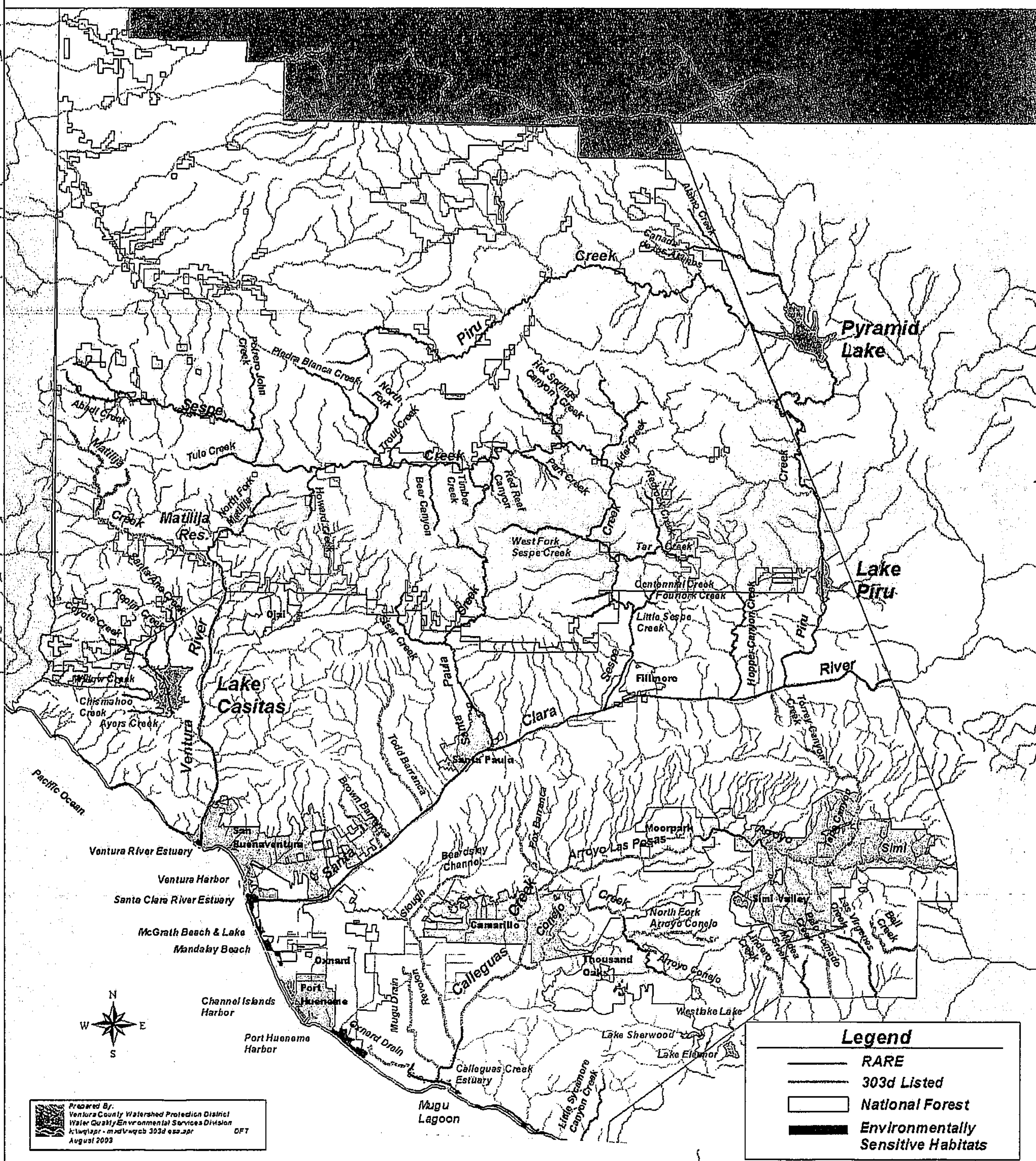
Final
Environmentally Sensitive Areas

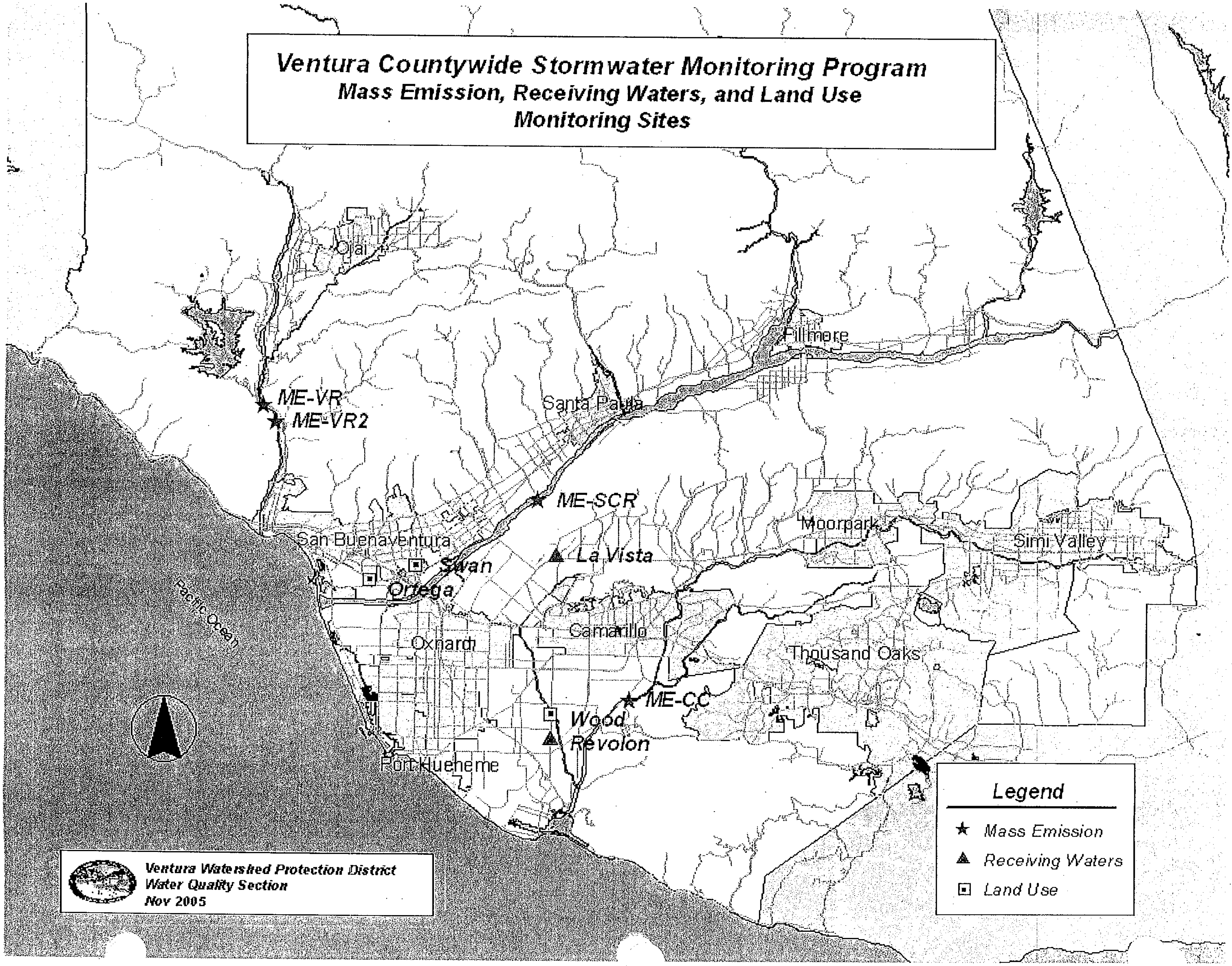
Each Permittee shall require the implementation of SQUIMP provisions no later than July 27, 2002, for all projects located in or directly adjacent to or directly discharging to an ESA, where the development will:

- *Discharge stormwater and urban runoff that is likely to impact a sensitive biological species or habitat; and*
- *Create 2,500 square feet or more of impervious surface area.*

Development and/or re-development of a single family home is exempt.

ESAs will include Clean Water Act 303d Listed Water Bodies in all reaches that are unimproved, all California Coastal Commission's Environmentally Sensitive Habitat Areas as delineated on maps in Local Coastal Plans and Regional Water Quality Control Board's Basin Plan Rare, Threatened or Endangered Species (RARE) sites. The California Department of Fish and Game's Significant Natural Areas map will be considered for inclusion as the department field verifies the designated locations.




Ventura Countywide Stormwater Monitoring Program
Mass Emission, Receiving Waters, and Land Use
Monitoring Sites
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Fillmore
ME-VR
ME-VR2
Santa Paula
ME-SCR
Moorpark
Simi Valley
San Buenaventura
La Vista
Swan
Ortega
Pacific Ocean
Camarillo
Oxnard
Thousand Oaks
ME-CC
Wood
Revolon
Port Hueneme
Legend
Mass Emission
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Ventura Watershed Protection District
Water Quality Section
Nov 2005

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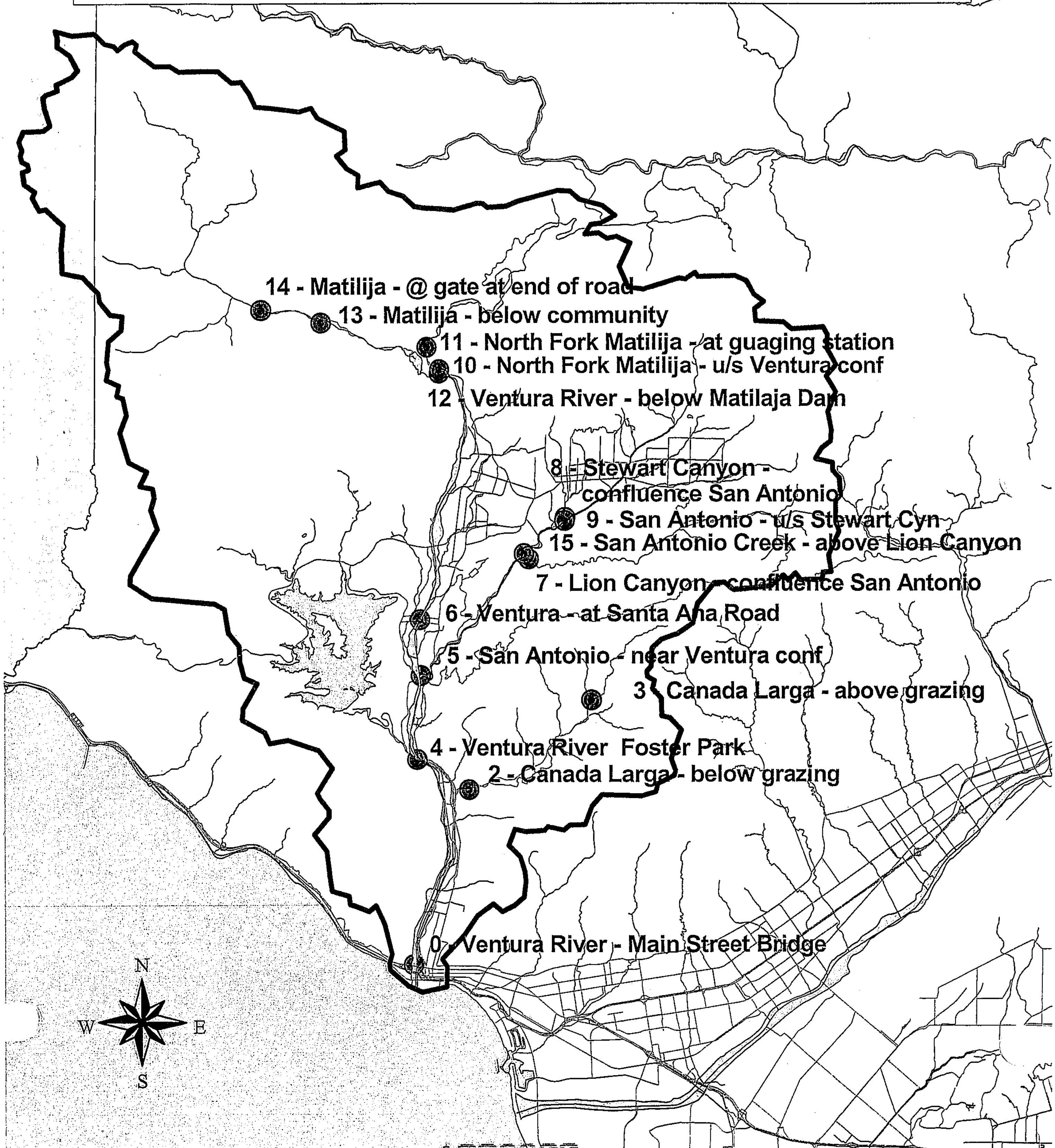
Ventura County Watershed Protection District

Ventura River Watershed

Bioassessment Monitoring Sites



Map: The City of San Buenaventura

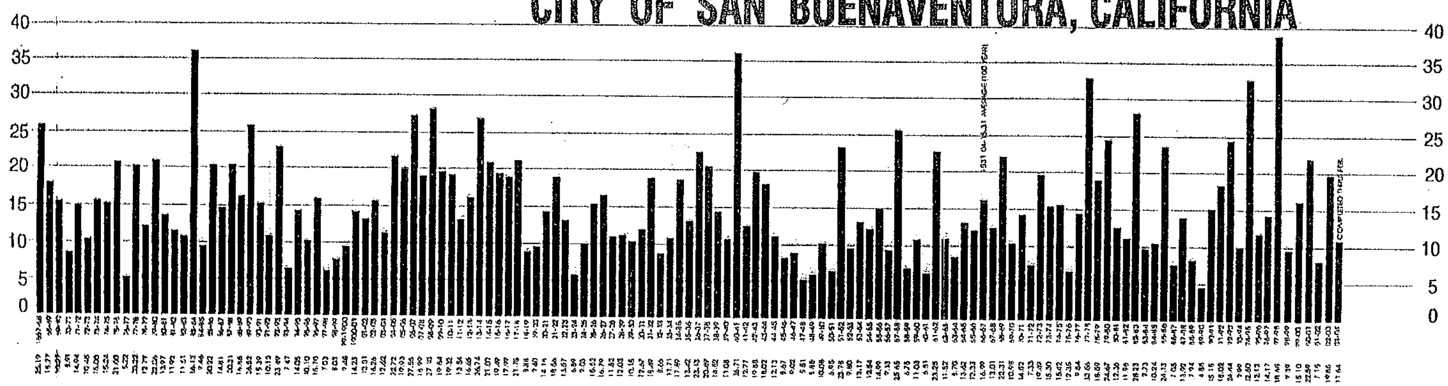
Map: The City of San Buenaventura

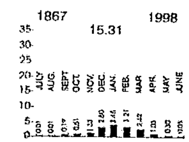
"OLD TIMERS" RAINFALL CHART
For
CITY OF SAN BUENAVENTURA, CALIFORNIA

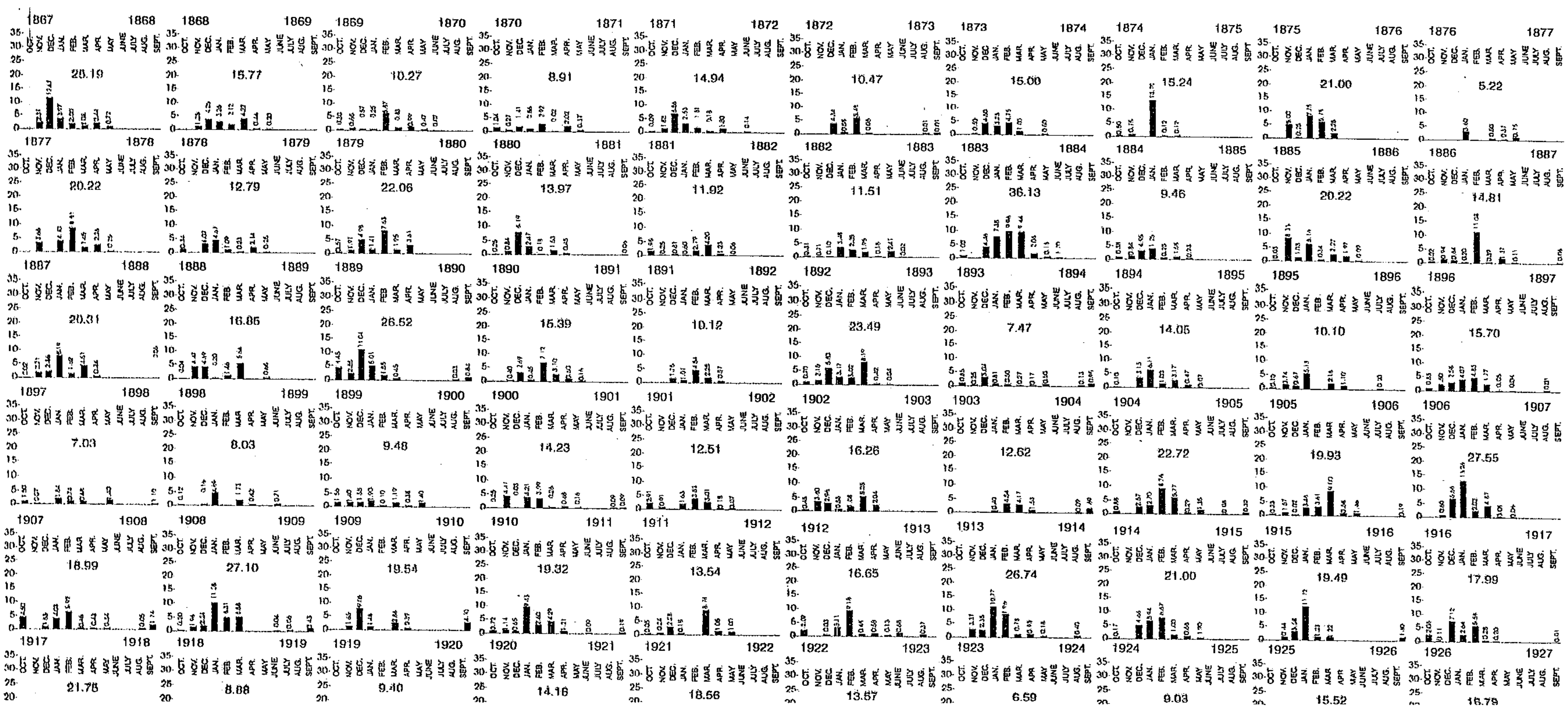
COMPILED FROM RECORDS

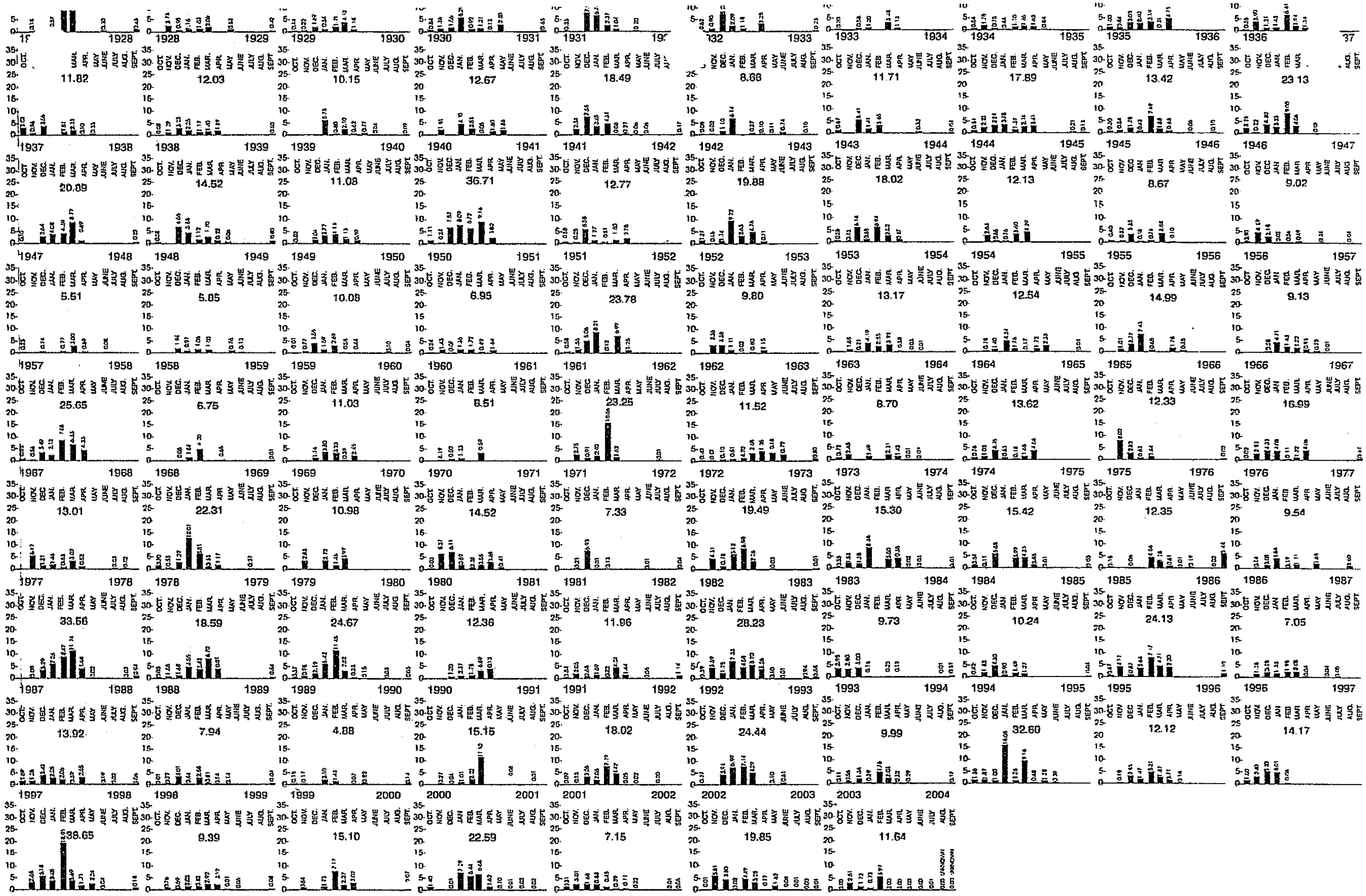
PRIOR TO 1873	HISTORY OF SANTA BARBARA AND VENTURA COUNTIES BY THOMPSON WEST-1883.
1873 TO 1900 -	VENTURA FREE PRESS AND CITY ENGINEERS OFFICE
1900 TO 1940 -	FRANK FERAUD.
1940 TO 1961 -	VENTURA COUNTY STAR- FREE PRESS.
1961 TO 1968 -	COUNTY DEPARTMENT OF WATER RESOURCES (Sta. No 131)
1968 TO 19 -	COUNTY DEPARTMENT OF WATER RESOURCES (Sta. No 66)

ORIGINATOR:
R.B. LEWIS RCE 3649
1886-1975
VENTURA, CALIFORNIA









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Map: Urban Runoff Quality Management Areas

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Map: Urban Runoff Quality Management Areas

Map: Agricultural Land Use in Western Ventura County

Map: Agricultural Land Use in Western Ventura County