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Guidance for Federal Land Management in the Chesapeake Bay Watershed

Chapter 3. Urban and Suburban

Nonpoint Source Pollution
Office of Wetlands, Oceans, and Watersheds
U.S. Environmental Protection Agency

Chapter 3.
Urban and Suburban

Contents

1 Introduction

1.1 Need for Urban and Suburban Runoff Guidance Update

1.1.1 Purpose

This chapter was developed to provide guidance on the most up-to-date, proven, and cost-effective practices for controlling urban and suburban runoff for federal land management in the Chesapeake Bay region, as required by Executive Order 13508. Federal agencies in the Chesapeake Bay watershed will find this guidance useful in managing urban runoff from the development and redevelopment of federal facilities and other land areas owned or managed by the federal government.

At the same time, EPA recognizes that the great majority of land in the Chesapeake Bay watershed is nonfederal land and is managed by private landowners, states, and local governments. Indeed, the vast majority of actions to restore the Chesapeake Bay will need to take place on nonfederal lands and will need to be implemented by nonfederal actors. From the perspective of land management and water quality restoration/protection, the same set of "proven cost-effective tools and practices that reduce water pollution" are appropriate for both federal and nonfederal land managers to restore and protect the Chesapeake Bay.

Therefore, states and others (e.g., states, local governments, conservation districts, watershed groups, developers, and other citizens in the Chesapeake Bay watershed) could choose to use this guidance document to the extent that they find it relevant and useful to their needs. The document presents practices and actions that are not unique to federal lands and thus will often be applicable to lands that are managed by nonfederal land managers. Thus, while this document has been written specifically to address the needs of federal land managers, other parties might also find it a useful guide to implementing the most effective and cost-effective practices available to restore and protect the Chesapeake Bay.

In addition, many of the nutrient and sediment sources in the Chesapeake Bay watershed are similar to sources in other watersheds around the country. Many of the practices needed to protect and restore the Chesapeake Bay are the same as or very similar to those used in other watersheds. Indeed, while great efforts have been made in preparing this document to assure the consideration of all relevant data for the Chesapeake Bay watershed, has been considered and used as appropriate in preparing and publishing this guidance, EPA has also employed data from outside the Chesapeake Bay watershed when it was deemed to be relevant and applicable to the Chesapeake Bay. For that reason, much of the information provided in this chapter is relevant to other areas of the United States. Therefore, practitioners outside the watershed might wish to consider this chapter as they develop and implement their own watershed plans and strategies to address nutrient and sediment pollution from nonpoint sources.

The primary approaches recommended in this chapter to protect the Chesapeake Bay and its tributaries—as well as waters in much of the rest of the United States—from the effects of development are to use green infrastructure/low impact development (LID) approaches and planning and development techniques, such as smart growth, that minimize the detrimental effects of development on the environment. Section 2 of this chapter focuses on such approaches.

The objective of green infrastructure/LID is to maintain or restore the predevelopment site hydrology in regard to the temperature, rate, volume, and duration of runoff flow. That can be accomplished during development, redevelopment, or retrofit. In some cases, achieving more runoff retention might be necessary for water quality protection, and this document does not preclude setting that performance objective. More specifically, this approach is intended to maintain or restore stream flows such that receiving waters, and stream channels, are not negatively affected by changes in runoff. That approach protects predevelopment hydrology and provides significant reductions in pollutant runoff. However, in some circumstances, specific additional pollutant control practices, (e.g., source controls) will need to be implemented to address pollutant runoff, and Section 3 of this chapter addresses those practices.

Planning can help guide development to areas that minimize effects on sensitive resources and natural areas. Planning can help ensure that new and redevelopment sites are designed to reduce runoff volume through on-site stormwater retention.

This chapter

- Emphasizes replicating predevelopment hydrology with respect to runoff volume, temperature, rate, and duration as a more reliable and effective stormwater management practice than traditional approaches that focus on pollutants without addressing hydrology. That emphasis is already expressed in a number of recent EPA documents and numerous states, cities, and expert groups, including the National Academy of Sciences (http://epa.gov/greeninfrastructure).
- Incorporates by reference the *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act*, EPA 841-B-09-001 (USEPA 2009e), which provides the hydrologic analysis for this approach. Elements of that document are referenced here,

but it is not repeated in its entirety; it is provided at http://www.epa.gov/owow/nps/lid/section438/.

- Builds on that technical guidance by providing users with sources to the newest research on key management practices and approaches and refers the reader to other resources where appropriate.
- Emphasizes those practices that can have multiple associated benefits, including cost-effectiveness and energy-savings. Some of those practices, in fact, cost less than the conventional stormwater management alternative in addition to providing other environmental and societal benefits.
- Addresses technical management practices for restoring and maintaining surface water quality. Green infrastructure/LID is generally used for managing smaller storm events that compose the bulk of annual rainfall and therefore contributes the most to both pollutant loading and stream degradation. This document does not address other stormwater issues, primarily flood-control or stormwater program management. However, those issues are addressed at length in documents referenced here.

Such an approach of maintaining predevelopment hydrology is already required for federal facilities by the Energy Independence and Security Act (EISA) of 2007 (P.L. 110-140, H.R. 6) section 438. Subsequent EPA guidance (EPA 841-B-09-001) (USEPA 2009e) provides advice on how to implement it at federal facilities.

EISA mandates certain federal facilities to comply with the following:

> **Stormwater runoff requirements for federal development projects.** The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.

State and local stormwater programs established under the Clean Water Act Amendments of 1987 were traditionally established to control pollutants that are associated with municipal and industrial discharges, e.g., nutrients, sediment, and metals. Increases in runoff volume and peak discharge rates have been regulated through state and local flood control programs but in many states have not been significantly addressed with regard to their role in water quality and habitat protection. Knowledge accumulated during the past 20 years has led to the conclusion that conventional approaches to control runoff have not resulted in adequate protection of the nation’s water resources, and, in fact, have had detrimental effects associated with increased volumes of runoff (National Research Council 2008).

An example of that detrimental effect is referenced in Figure 3-1.

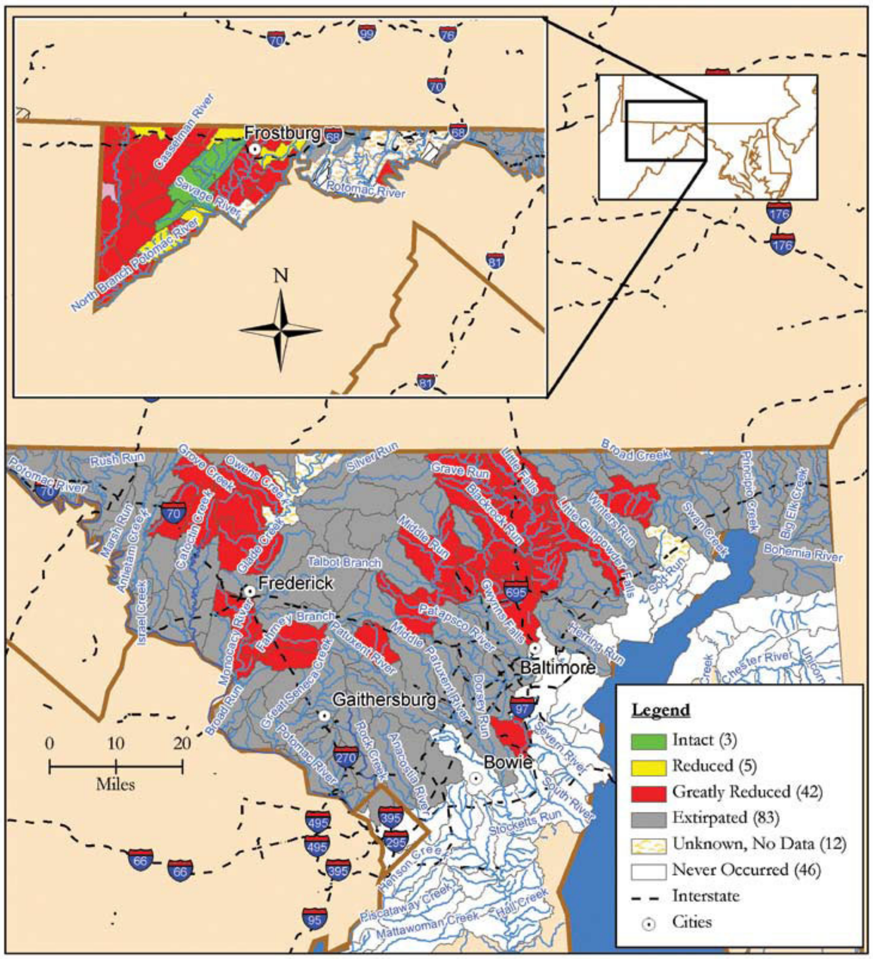
This chapter emphasizes site-specific management practices from green infrastructure/LID that are driven by locally applicable performance objectives. Each site or watershed has its own unique circumstances—a combination of land uses, water resource needs, environmental conditions, regulatory drivers, and community attributes—that will affect which approaches are the most successful in terms of effectiveness and community acceptance. The means selected will vary depending on the development setting and site-specific opportunities and constraints; however, designing to replicate predevelopment hydrology is the overall goal that best ensures achieving full designated uses of the waters. In cases where green infrastructure/LID is not feasible on-site or is otherwise inadequate to meet water quality objectives, additional measures should be considered, as discussed in Section 3 of this chapter.

The past decade has brought significant growth in the use of approaches that seek to control runoff volume at the site scale using a variety of decentralized stormwater controls and runoff retention methods that have the objective of replicating the predevelopment hydrology as much as technically feasible. That type of holistic, hydrology-based approach to urban runoff management is termed *low impact development* or LID (also referred to variously as better site design, environmentally sensitive design, sustainable stormwater management, and *green infrastructure*, among others). The approach has been proven to be technically achievable and cost-effective; examples demonstrating this are provided in Figures 3-2 and 3-3 that describe projects in Portland, Oregon, and in coastal North Carolina.

The purpose of this chapter is to present an overview of the practices and resources available for federal facilities and others to achieve water quality goals in the most cost-effective and potentially successful manner, with the overall objective of improving water quality, habitat, and the environmental and economic resources of the Chesapeake Bay and its tributaries.

A Maryland Department of Natural Resources (DNR) study highlights the detrimental impact that development, loss of forest, and temperature changes have had on brook trout, Maryland's only native trout species, based on three decades of study.

For every one percent increase in impervious land cover in a stream's watershed, the odds of brook trout survival decreased by nearly 60 percent (Stranko, et.al. 2008).



Map data derived from state and federal data and compiled in EBTJV assessment results titled, *Distribution, status, and perturbations to brook trout within the eastern United States, 2006.* Authored by Mark Hudy, US Forest Service; Teresa Thieling, James Madison University; Nathaniel Gillespie, Trout Unlimited; Eric Smith, Virginia Tech. Map created on 2/24/06 by Nathaniel Gillespie, Source: *Eastern Brook Trout: Status and Threats, Maryland,* Trout Unlimited, brochure. www.tu.org/atf/cf/%7BED0023C4-EA23-4396-9371-8509DC5B4953%7D/brookie_MD.pdf. Eastern Brook Joint Trout Venture.

Figure 3-1. Maryland Department of Natural Resources study (2008) and Trout Unlimited mapping (2006) document the extensive loss of brook trout from development impacts.

Portland Bureau of Environmental Services (BES) Tabor to the River project integrates hundreds of sewer, green stormwater management, tree planting and other watershed projects to improve sewer system reliability, stop sewer backups in basements and street flooding, control combined sewer overflows (CSOs) to the Willamette River, and restore watershed health.

The 1,472-acre basin is high-density residential development, with commercial land use, and approximately 37% impervious. The Tabor to the River project will address stormwater management and watershed health by

- Adding 500 LID facilities in the public right-of-way (curb extensions, vegetated planters, and flow restrictors)
- Addressing Runoff from 8 acres of parking and rooftops on private property controlled by LID facilities (e.g., vegetated planters, rain gardens, eco-roofs)
- Planting two revegetation projects to remove invasive species
- Planting 3,500 trees in the city's right-of-way
- Conducting Neighborhood education and project outreach
- Improving access to the Willamette River from an adjacent neighborhood

Sources:
Portland BES Web site for Tabor to the River: http://www.portlandonline.com/bes/index.cfm?c=47591

Tsurumi, Naomi and Bill Owen *Painting it Green—Replacing an All-Pipe Solution with an Integrated Solution Emphasizing Low Impact Development;* American Society of Civil Engineers (ASCE), Low Impact Development Conference Proceedings, 2008.

Figure 3-2. LID *Green Streets* save Portland, Oregon, nearly $60 million while restoring water quality.

Using LID on a development project in Middlesound, North Carolina, where LID is encouraged to protect shellfish beds and coastal recreational waters, the developer saved money and realized marketing advantages compared to tradition stormwater design:

- Gained 3 to 4 additional lots (from 56 to 59)
- Reduced stormwater pipe by 89%
- Decreased road widths 9%
- Eliminated 9,000-ft curb and gutter
- Eliminated 5 infiltration basins
- Eliminated 5 monitoring wells
- Eliminated 10,000 linear feet of stormwater force main
- Saved $1.5 million in fill material
- Increased localized stormwater infiltration
- Eliminated 3 stormwater pumps
- Increased functional and recreation open space
- Minimized wetlands intrusion and wildlife impacts
- Buyers prefer *green* real estate
- Promotes good neighbor
- Decreased construction traffic

"Your ideas and preliminary plans for incorporating LID for Ridgefield are proving invaluable. After having it approved for a conventional stormwater system, we were concerned with the extreme costs of the system and development's financial feasibility. However, with the utilization of an LID stormwater system we can dramatically reduce the costs and make the project viable again. In our estimates we are projecting a savings up to $1.5 million and adding 4 lots. In addition, we will be saving many of the natural features and topography resulting in a 'greener,' more conservation oriented neighborhood."

—Ridgefield Property Developer, February 2009

Source:
Todd Miller, North Carolina Coastal Federation; Heather Burkert, and H.K Burkert & Co.

Figure 3-3. Developer realizes savings and marketing value with LID while better protecting coastal waters.

1.1.2 Intended Audience

The primary audience for this chapter is stormwater managers in federal agencies and at the local, state, and federal levels who are responsible for meeting water quality goals and implementing water quality programs in developing and developed areas.

Others who can benefit from the information in this chapter include the development community and its multidiscipline designers, because new and redevelopment projects offer the best opportunity to implement stormwater controls to mitigate development's effects on water resources; local public officials responsible for land use and water quality decision making, academia and research groups, environmental and community organizations, and the business community.

1.1.3 Water Quality Significance of Urban Runoff in the Chesapeake Bay Watershed

Urban stormwater runoff is responsible for a significant portion of the nitrogen (N), phosphorus (P), and sediment loading to the Chesapeake Bay. The loading has been continuing to increase over time because of development. Understanding the core cause of this problem is essential to reducing this source.

This section contains background information on the causes and consequences of stormwater discharges, i.e., the alterations to natural hydrology and the resulting impacts, and solutions that can be used to address the causes and consequences of stormwater discharges, and how to implement those solutions such that they will be applicable to all areas of the country and comply with section 438 of EISA.

Under natural, undisturbed conditions in the mid-Atlantic region, most rainfall is intercepted by vegetation, infiltrates into the soil where it feeds streams and aquifers, or is returned to the atmosphere via evapotranspiration. Very little rainfall becomes stormwater runoff, and runoff generally occurs only with larger precipitation events. Traditional development practices cover large areas of the ground with impervious surfaces such as roads, parking lots, driveways, sidewalks, and buildings. Once such development occurs, rainwater cannot infiltrate into the ground and as a result, runs off the site at rates and volumes that are much higher than would naturally occur. Under developed conditions, runoff occurs even during small precipitation events that would normally be absorbed by the soil and vegetation. The collective force of the increased runoff scours streambeds, erodes streambanks, and causes large quantities of sediment and other entrained pollutants to enter the waterbody each time it rains (Shaver et al. 2007; Walsh et al. 2005; Booth testimony 2008). Such change in runoff with urbanization is illustrated in Figure 3-4. Studies of historical temperature patterns in streams recently documented increases in temperature in many areas; areas in the Chesapeake Bay region where statistically significant stream temperature increases have occurred include the Potomac River, the Patuxent River, and the Delaware River near Chester, Pennsylvania (Kauskai 2010; http://www.chesapeakebay.net/news_streamtemps10.aspx?menuitem=50656).

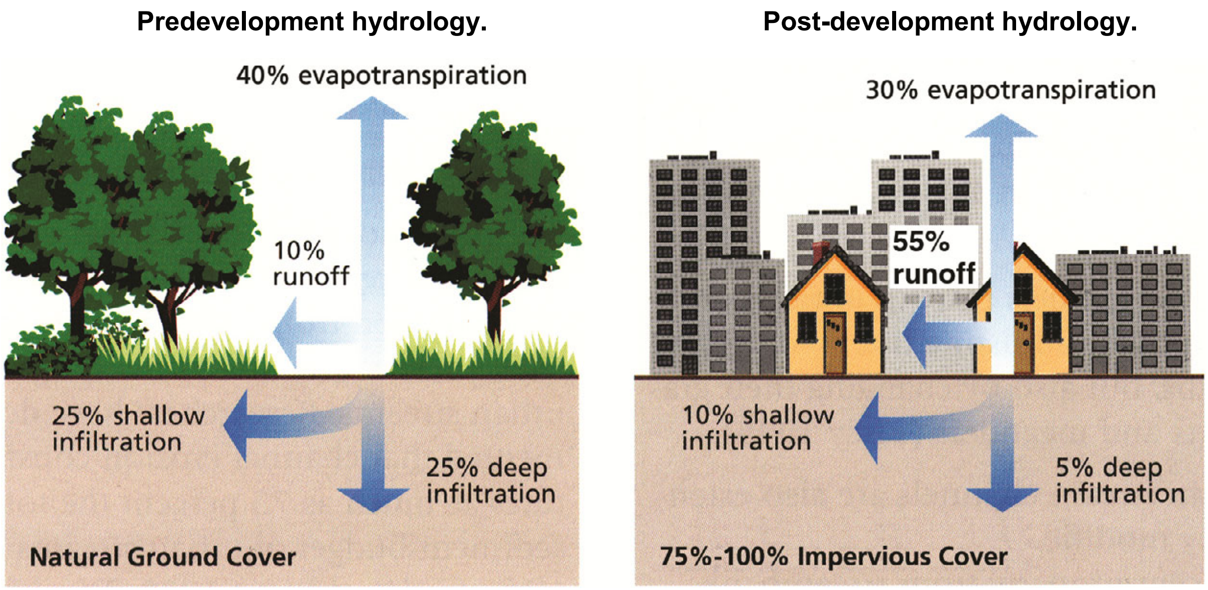


Figure 3-4. Predevelopment and post-development hydrology (USDA).

In recognition of those problems, stormwater managers employed extended detention approaches to mitigate the effects of increased runoff peak runoff rates. However, wet ponds and similar practices inadequately protect downstream hydrology because of the following inherent limitations of the conventional practices (National Research Council 2008; Shaver et al. 2007):

- Poor peak control for small, frequently occurring storms
- Negligible volume reduction
- Increased duration of peak flow

Detention storage targets relatively large, infrequent storms, such as the 2- and 10-year/24-hour storms for peak flow rate control. As a result of that design limitation, flow rates from smaller, frequently occurring storms typically exceed those that existed on-site before land development occurred, and those increases in runoff volumes and velocities typically result in flows erosive to stream channel stability (Shaver et al. 2007). Section 438 of EISA is intended to address the inadequacies of the historical detention approach to managing stormwater and promote more sustainable practices that have been selected to maintain or restore predevelopment site hydrology.

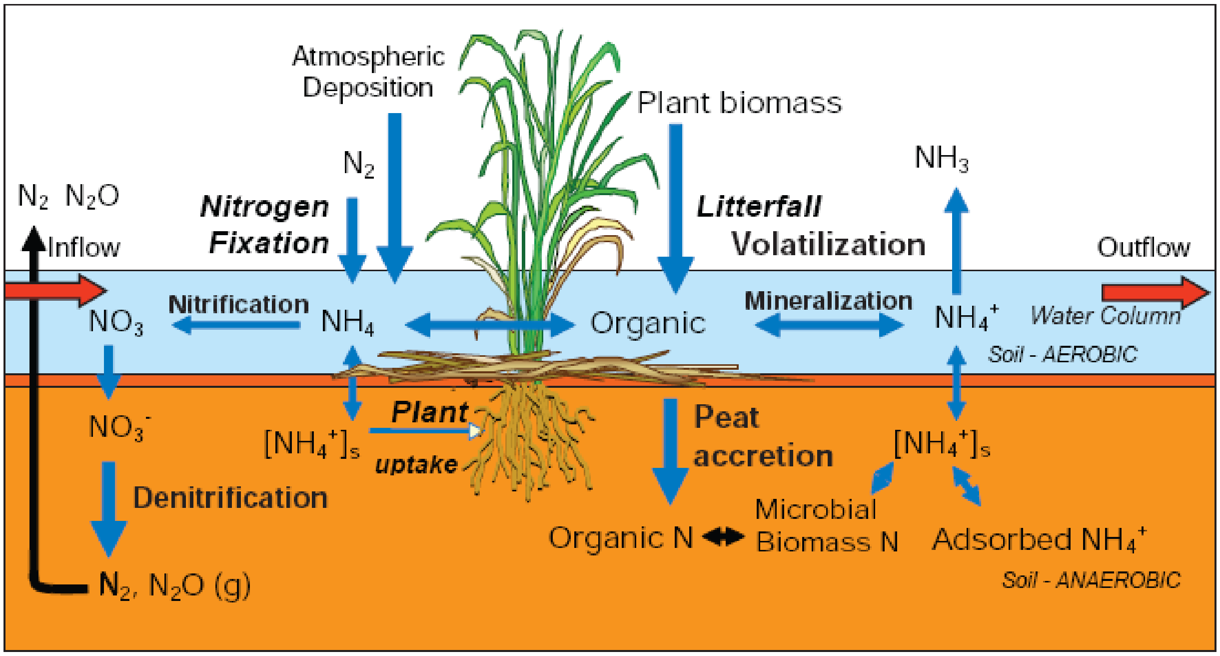
A 2008 National Research Council report on urban stormwater confirmed the shortcomings of current stormwater control efforts. Three of the report's findings on stormwater management approaches are particularly relevant (National Research Council 2008).

- Individual controls on stormwater discharges are inadequate as the sole solution to stormwater in urban watersheds.
- Stormwater control measures such as product substitution, better site design, downspout disconnection, conservation of natural areas, and watershed and land-use planning can dramatically reduce the volume of runoff and pollutant load from new development.
- Stormwater control measures that harvest, infiltrate, and evapotranspire stormwater are critical to reducing the volume and pollutant loading of small storms.

The amount of water on Earth today is the same as it was billions of years ago. Water is continually recycled through the water cycle (or hydrologic cycle), a system that moves rainfall from the atmosphere to land, through surface and groundwater systems, to the ocean, and back into the atmosphere. Water changes its form throughout this cycle between solid, liquid, and gas—and it moves over the Earth's surface, underground, or through the atmosphere.

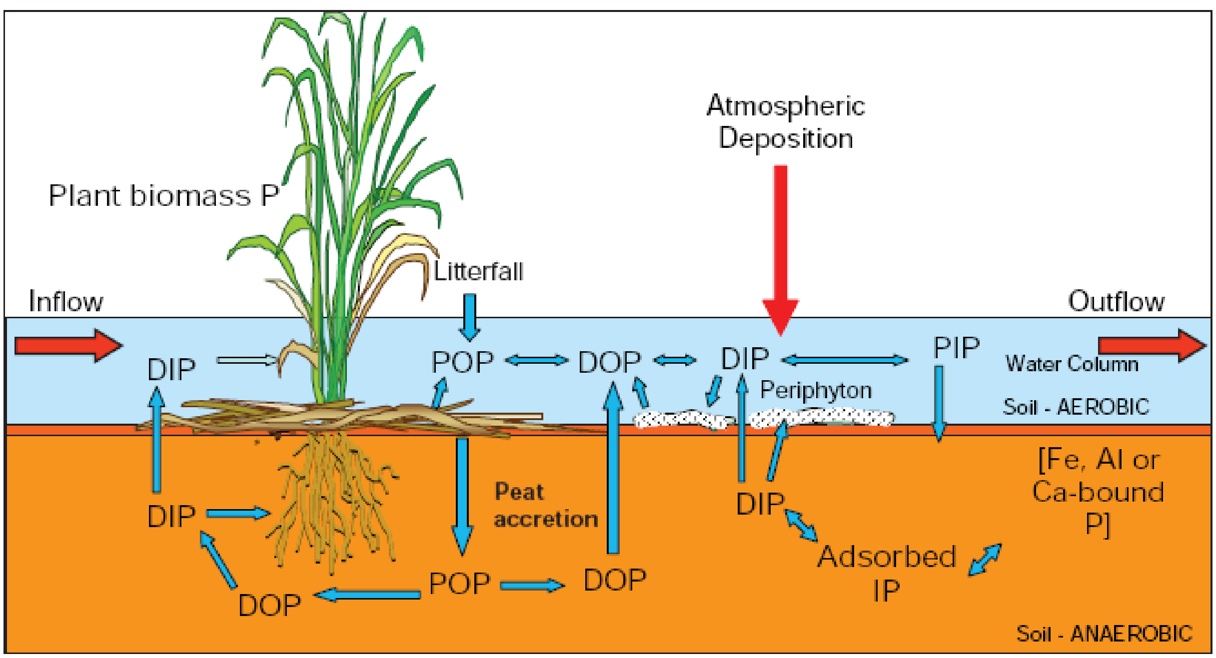
The hydrologic cycle is a dynamic system of interdependent parts in constant movement. Altering one part of the cycle affects other parts because the overall water balance must be maintained. Removing trees and paving land surfaces, for example, reduces the amount of infiltration and evapotranspiration and increases the amount of runoff. Additional information on the hydrologic cycle and how it affects the design of stormwater management practices is in *Stormwater Best Management Practice Design Guide* (EPA/600/R-04/121, September 2004, http://www.epa.gov/nrmrl/pubs/600r04121/600r04121.pdf).

The nutrient cycle is also a dynamic, interdependent process. Development affects soil, groundwater, and surface water and disrupts the balance, ultimately resulting in damaging environmental conditions such as those present in the Chesapeake Bay. Schematic representations of the N and P cycles in wetlands are provided in Figures 3-5 and 3-6. Additional information on nutrient cycling is available in *Nutrient Criteria Technical Guidance Manual, Wetlands* (EPA-822-B-08-001, 2008f).



Source: USEPA 2008f

Figure 3-5. N cycling in wetlands.



Source: USEPA 2008f

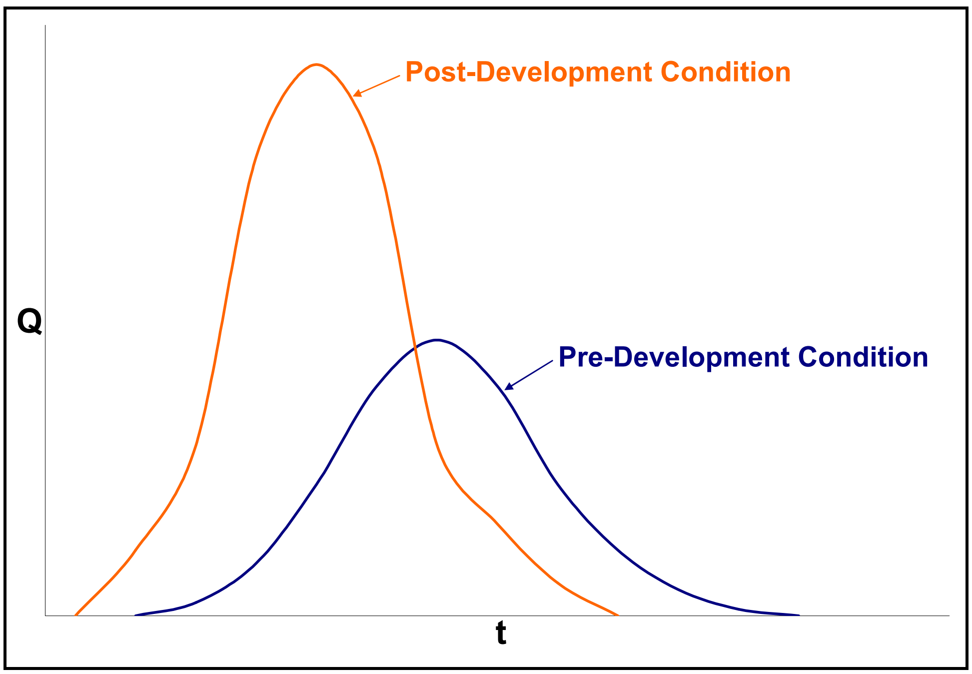
Figure 3-6. P cycling in wetlands shown dissolved inorganic phosphorus (DIP), dissolved organic phosphorus (DOP), particulate organic phosphorus (POP).

Land cover changes that result from site development include increased imperviousness, soil compaction, loss of vegetation, and loss of natural drainage patterns resulting in increased runoff volumes and peak runoff rates. The cumulative effects of the land cover changes result in alterations of the natural hydrology of a site, which disrupts the natural water balance and changes water flow paths. The consequences of these impacts include the following:

- *Increased volume of runoff.* With decreased area for infiltration and evapotranspiration because of development, a greater amount of rainfall is converted to overland runoff, which results in larger stormwater discharges.
- *Increased peak flow of runoff*. Increased impervious surface area and higher connectivity of impervious surfaces and stormwater conveyance systems increase the flow rate of stormwater discharges and increase the energy and velocity of discharges into the stream channel.
- *Increased duration of discharge*. Detention systems generate greater flow volumes for extended periods. Those prolonged, higher discharge rates can undermine the stability of the stream channel and induce erosion, channel incision and bank cutting.
- *Decreased baseflow and increased flash flooding*. Changes to baseflow are caused by alterations to the hydrologic cycle created by land cover changes and increased imperviousness, which prevents rain from recharging groundwater, where it serves as baseflow for streams. Such changes increase the *flashiness* of streams, resulting in elevated flows during or after storm events, and greatly diminished baseflows in between storms.
- *Increased pollutant loadings*. Impervious areas are a collection site for pollutants. When rainfall occurs, the pollutants are mobilized and transported directly to stormwater conveyances and receiving streams via the impervious surfaces.
- *Increased temperature of runoff*. Impervious surfaces absorb and store heat and transfer it to stormwater runoff. Higher runoff temperatures can have detrimental effects on receiving streams. Detention basins magnify this problem by trapping and discharging runoff that is heated by solar radiation (Galli 1991; Schueler and Helfrich 1988).
- *Habitat modifications and stream morphology changes.* Increased runoff rate and volume alter stream morphology. Highly erosive stormwater can wash out in-stream structures that serve as habitat. Large storms deepen, widen, and straighten channels, disconnecting streams from their floodplains and destroying meanders that serve to dissipate hydraulic energy (Walsh et al. 2005).

The resulting increases in volume, peak flow, and duration are illustrated in the hydrograph in Figure 3-7, which is a representation of a site's stormwater discharge with respect to time. The hydrograph illustrates the effects of development on runoff volume and timing of the runoff.

Individual points on the curve represent the rate of stormwater discharge at a given time. The graph illustrates that development and corresponding changes in land cover result in greater discharge rates, greater volumes, and shorter discharge periods. In a natural condition, runoff rates are slower than those on developed sites, and the discharges occur over a longer period. The predevelopment peak discharge rate is also much lower than the post-development peak discharge rate because of attenuation and absorption by soils and vegetation. In the post-development condition, there is generally a much shorter time before runoff begins because of increased impervious surface area, a higher degree of connectivity of those areas, and the loss of soils and vegetative cover that slow or reduce runoff. Simply reducing the peak flow rate, and extending the duration of the predevelopment peak flow, is not effective because as the different discharge sources enter a stream, the hydrographs are additive, and the extended predevelopment peak flows combine to produce an overall higher than natural peak. The result is the pervasive condition of channel incising, erosion, and loss of natural stream biological and chemical function as observed in Figure 3-8.



Note: Q = volumetric flow rate; t = time

Figure 3-7. Post-development hydrograph shows how development results in increased peak flow, shorter duration, and increased overall volume.

Figure 3-8. Stream displaying the effects of stormwater runoff and channel downcutting.

1.1.4 Managing Urban Runoff to Reduce Nutrients and Sediment Loss

1.1.4.1 Preserving and Restoring Hydrology

Green infrastructure practices include a wide variety of practices that use such mechanisms. They can be used at the site (Figure 3-9), neighborhood, and watershed/regional scales. In this document, the focus is on site-level practices, such as bioretention and water harvesting, but it also addresses the land management scales of planning (i.e., planning techniques such as smart growth), and site design (i.e., site design techniques such as conservation development).

Restoring or maintaining predevelopment hydrology has emerged as a control approach for several reasons. Most importantly, the approach is intended to directly address the root cause of impairment. Current control approaches have been selected in an attempt to control the symptoms (peak flow, and excess pollutants), but the strategy is ineffectual in many cases because of the scale of the problem, the cumulative effects of multiple developments and the need to manage both site and watershed level effects. With current approaches, it is also difficult to adequately protect and improve water quality because the measures employed are not addressing the root problem, which is a hydrologic imbalance.

Designing facilities with the goal of maintaining or restoring predevelopment hydrology provides a site-specific basis and an objective methodology with which to determine appropriate practices to protect the receiving environment.

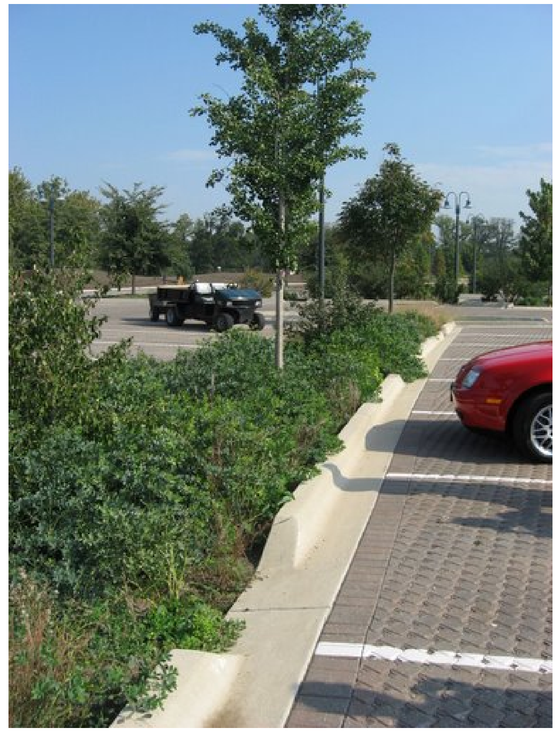


Figure 3-9. Parking lot bioswale and permeable pavers in Chicago.

Using predevelopment hydrology as the guiding control principle also allows the designer to consider climatic and geologic variability, and tailor the solutions to the project location. Thus, the one-size-fits-all approach is not appropriate because the design objective is dictated by the predevelopment site conditions and other technicalities of the project site and facility use. Site assessments of historical infiltration and runoff rates will inform the designer and provide the basis for a suitable design. The use of this approach will minimize compliance complications that can arise from prescriptive design approaches that do not account for the variability of precipitation frequencies, rainfall intensities, and land cover and soil conditions that influence infiltration and runoff.

More information on addressing hydromodification and riparian buffers are provided in separate volumes of this document.

1.1.4.2 Defining Green Infrastructure/LID

LID is a stormwater management strategy that many localities across the country have adopted. Green infrastructure is a term also used to describe LID practices, with the connotation that such practices can be thought of as infrastructure, just like a pipe or other structural management practice. Green infrastructure/LID is a stormwater management approach and set of practices that can be used to reduce runoff and pollutant loadings by managing the runoff as close to its source(s) as possible. A set or system of small-scale practices, linked together on the site, is often used. LID approaches can be used to reduce the effects of development and redevelopment activities on water

Examples of LID Practices

- Infiltration basins and trenches
- Permeable pavement
- Disconnected downspouts
- Rain gardens and other vegetated treatment systems

resources. In the case of new development, LID is typically used to achieve or pursue the goal of maintaining or closely replicating the predevelopment hydrology of the site. In areas where development has already occurred, LID can be used as a retrofit practice to reduce runoff volumes, pollutant loadings, and the overall effects of existing development on the affected receiving waters.

In general, implementing integrated LID practices can result in enhanced environmental performance while at the same time reduce development costs when compared to traditional stormwater management approaches of collection, piping, and pond storage for treatment by settling. LID techniques promote the use of natural systems, which can effectively reduce nutrients, pathogens, and metals from stormwater through runoff volume reduction, filtration, and other processes. These systems can be designed to accommodate or bypass larger flows when large rain events occur, when the LID practice is sized for small rain events.

Cost savings can be achieved in reduced infrastructure, particularly in new development where land is available for surface practices, because the total volume of runoff to be managed is minimized through infiltration and evapotranspiration. By working to mimic the natural water cycle, LID practices protect downstream resources from pollutants and adverse hydrologic impacts that can degrade stream channels and harm aquatic life.

The use of LID does present challenges in operations and maintenance (O&M) because of the highly distributed nature of the controls. The large number and distributed nature of LID practices makes it challenging to track, inspect and maintain them. Depending on how the program is implemented, many LID practices can be on private property within drainage easements obtained for that purpose. New institutional frameworks for managing LID operations responsibly are being developed and will continue to be developed.

It is important to note that LID designs usually incorporate more than one type of practice or technique—in series as a treatment train or parallel to manage small drainage areas. That approach helps to provide integrated treatment of runoff from a site. For example, in lieu of a treatment pond serving a new subdivision, planners might incorporate a bioretention area in each yard, disconnect downspouts from driveway surfaces, remove curbs or cut out drainage slots into curbs, and install grassed swales in common areas. The basis of LID is integrating small practices throughout a site instead of using extended detention wet ponds for treatment purposes.

Planning techniques such as smart growth minimize runoff by approaches such as enhancing density along existing transportation and other infrastructure corridors, and reducing sprawl and greenfield development. While one aspect of smart growth—increased population density where appropriate—has been perceived as potentially conflicting with LID approaches that have typically been considered as land-intensive for infiltration, in actuality they can be compatible and complementary. In dense, high-rise urban areas, stormwater management practices such as expanded street tree boxes, building-front infiltration planter boxes, green roofs and permeable pavement with infiltration potential, can provide improved water quality and needed aesthetic relief from endless paved and concrete surfaces. During warm weather, the urban heat island effect is intensified by the paved surfaces. The need for integrating green stormwater management will become more essential as people move into and live in dense areas.

Smart Growth Includes:

- Conservation of resources by reinvesting in existing infrastructure, infill development, reclaiming historic buildings, with denser growth along transit.
- Design of neighborhoods that have shops, offices, schools and other amenities near homes, giving residents and visitors the option of walking, bicycling, taking public transportation, or driving
- Economically competitive, desirable places to live, work, play

Conservation designs minimize runoff by conserving undeveloped land and reducing the amount of impervious surface, which can cause increased runoff volumes. Open space can be used to treat the increased runoff from the built environment through infiltration and evapotranspiration. For example, developers can use conservation designs to preserve important features on the site such as wetland and riparian areas, forested tracts, and areas of pervious soils. Development plans that outline the smallest site disturbance minimize stripping topsoil and compacting subsoil. Such simplistic, nonstructural methods reduce the need to build runoff controls like retention ponds for treatment and larger stormwater conveyance systems, thereby decreasing the overall project cost. Reducing the total area of impervious surface by limiting road widths and parking areas also reduces the volume of runoff that must be treated. Conservation designs benefit residents and their quality of life because of increased access and proximity to communal open space, a greater sense of community, and expanded recreational opportunities. Some literature notes more developer profit from conservation designed subdivisions compared to conventional subdivisions (Mohamad 2006), but others note that regulations requiring clustered-type designs might be needed where lot size alone appears to be a stronger driver of value to consumers (Kopits et al. 2007).

Examples of Conservation Design

- Cluster development
- Undeveloped land conservation
- Reduced pavement widths (streets, sidewalks)
- Shared driveways
- Reduced setbacks (shorter driveways)
- Site fingerprinting during construction

LID practices are engineered structures or landscape features designed to capture and infiltrate, store, convey, or filter runoff in a manner that attempts to replicate predevelopment hydrology.

Infiltration practices can also be used to achieve a goal of recharging groundwater while at the same time reducing runoff. Recharging groundwater is especially important in areas where maintaining drinking water supplies and stream baseflow is of special concern because of limited precipitation or high withdrawal demands. Infiltration of runoff can also help to maintain stream temperatures because the infiltrated water that moves laterally to replenish stream baseflow typically has a lower temperature than overland flows, which might be subject to solar radiation. Another advantage of infiltration practices is that they can be integrated into landscape features in a site-dispersed manner. This feature can result in aesthetic benefits and, in some cases, recreational opportunities; for example, some infiltration areas can be used as playing fields during dry periods.

Runoff storage practices reduce the volume and peak rate of runoff to protect streams from the erosive forces of high flows, and irrigate landscaping to providing aesthetic benefits such as more sustainable (i.e., more self-watering) landscape islands, tree boxes, and rain gardens. Designers can take advantage of the space beneath paved areas like parking lots and sidewalks to provide additional storage. For example, underground vaults can be used to store runoff in both urban and rural areas, and street tree designs have been developed to better enable use of that space for root growth to enable establishment of healthy urban tree canopy.

Runoff Storage Practices

- Parking lot, street, and sidewalk storage in underground infiltrating vaults
- Rain barrels and cisterns
- Depressional storage in landscape islands and in tree, shrub, or turf depressions
- Green roofs

Runoff conveyance practices can be used to slow flow velocities, lengthen the runoff time of concentration, and delay peak flows that are discharged off-site. LID conveyance practices can be used as an alternative to curb-and-gutter systems. LID conveyance practices often have rough vegetative surfaces that reduce runoff velocities and allow settling of solids. They promote infiltration, filtration, and some biological uptake of pollutants. LID conveyance practices also can perform functions similar to those of conventional

Runoff Conveyance Practices

- Eliminating curbs and gutters
- Creating grassed swales and grass-lined channels
- Roughening surfaces
- Creating long flow paths over landscaped areas
- Creating terraces and check dams

curbs, channels, and gutters. For example, they can be used to reduce flooding around structures by routing runoff to landscaped areas for treatment, infiltration, and evapotranspiration.

Filtration practices capture pollutants by physical filtration of solids or cation exchange of dissolved pollutants. They also reduce runoff volume, recharge groundwater, increase stream baseflow, and reduce thermal impacts. Pollutant buildup can be of concern, and pollutants are typically captured in the upper soil horizon. Captured pollutants can be removed by replacing the topsoil. The useful life of the media can be extended by selecting plants that also provide phytoremediation.

Filtration Practices

- Bioretention/rain gardens
- Vegetated swales
- Vegetated filter strips/buffers

Conservation landscaping reduces labor, watering, and chemical use. Properly preparing soils and selecting species adapted to the site increases the success of plant growth, stabilizing soils and allowing for biological uptake of pollutants. Pest resistance (reducing the need for pesticides) and improved soil infiltration from root growth are among the goals. Conservation landscaping is promoted by many entities in the Chesapeake Bay area and elsewhere.

Conservation Landscaping

- Planting native, drought-tolerant plants
- Converting turf areas to shrubs and trees
- Reforestation
- Encouraging longer grass length
- Planting wildflower meadows rather than turf along medians and in open space
- Amending soil to improve infiltration
- Integrated pest management

1.1.4.3 Benefits of Designing to Restore and Preserve Predevelopment Hydrology

Unlike traditional stormwater management, an approach to maintain or restore predevelopment hydrology meets multiple performance objectives and can offer additional benefits, including the following:

Pollution abatement. LID practices more reliably reduce pollutant loadings by reducing the runoff volume. LID practices, to a lesser degree, can reduce pollutants by settling, filtering, adsorption, and biological uptake.

Protect downstream water resources. LID practices help to prevent or reduce hydrologic effects on receiving waters, reduce stream channel degradation from erosion and sedimentation, improve water quality, increase water supply, and enhance the recreational and aesthetic value of our natural resources. Other potential benefits include reduced incidence of illness from swimming and wading, more robust and safer seafood supplies.

Protect integrity of streams and floodplains to preserve ecological functions. Costs of streambank restoration can be reduced or avoided altogether where appropriate protection techniques are used, in particular those techniques that maintain predevelopment hydrology during development, redevelopment, and in retrofitting. Excess deposition of sediment in rivers and in estuaries can be minimized by preventing upstream erosion caused by stresses resulting from excess stormwater volume. Using LID techniques such as stormwater wetlands also can help protect or restore floodplains, which can be used as park space or wildlife habitat (Trust for Public Lands 1999).

Conserve energy and reduce carbon emissions in landscape irrigation and other non-potable uses. U.S. water-related energy use—for pumping, treating and heating water—has been estimated to be at least 521 million MWh a year. That is equivalent to 13 percent of the nation's electricity consumption, with a CO_2 output equal to the emissions of more than 62 coal fired power plants. *The Carbon Footprint of Water* (Griffiths-Sattenspiel and Wilson 2009; http://www.rivernetwork.org/blog/7/2009/05/13/carbon-footprint-water) notes

> Water conservation, efficiency, reuse and [LID] strategies should be targeted to achieve energy and greenhouse gas emissions reductions. Research from the California Energy Commission suggests that programs focusing on these kinds of water management strategies can achieve energy savings comparable to traditional energy conservation measures at almost half the cost. Water management policies that promote water conservation, efficiency, reuse and LID can reduce energy demand and substantially decrease carbon emissions.
>
> If LID techniques were applied in Southern California and the San Francisco Bay area, between 40,400 [million gallons] and 72,700 [million gallons] per year in additional water supplies would become available by 2020. The creation of these local water supplies would result in electricity savings of up to 637 million kWh per year and annual carbon emissions reductions would amount to approximately 202,000 metric tons by offsetting the need for inter-basin transfers and desalinated seawater.
>
> As the [United States] struggles to reduce its carbon emissions in response to global warming, investments in water conservation, efficiency, reuse and LID are among the largest and most cost-effective energy and carbon reduction strategies available.

Help achieve sustainability in environmental, energy, and economic performance. The multiple benefits can help to achieve sustainability. For example as in the requirements for federal facilities contained in the Executive Order on Federal Leadership in Environmental, Energy, and Economic Performance (October 5, 2009). The Executive Order includes requirements for federal facilities to increase energy efficiency; conserve water and support sustainable communities (http://www.whitehouse.gov/the_press_office/President-Obama-signs-an-Executive-Order-Focused-on-Federal-Leadership-in-Environmental-Energy-and-Economic-Performance/).

Groundwater recharge and stream baseflow. Growing water shortages nationwide increasingly indicate the need for holistic water resource management strategies. Development increases impervious surfaces and runoff. Infiltration practices replenish groundwater and increase stream baseflow. Adequate groundwater recharge is important because low groundwater levels can lead to low baseflows in dry weather. Greater fluctuations in stream flows and temperatures occur when rainfall does not infiltrate, to the detriment of aquatic life.

Water quality improvements/reduced treatment costs. Keeping water clean can prevent the costs for cleaning it up. The Trust for Public Land (1999) notes that Atlanta's tree cover has saved more than $883 million by preventing the need for stormwater facilities. A study by the Trust for Public Land and the American Water Works Association (2004) of 27 water suppliers found that higher forest cover in a watershed reduced water treatment costs. According to the study, approximately 50 percent of the variation in treatment costs can be tied to the percentage of forest cover. It also found that for every 10 percent increase in forest cover, treatment and chemical costs decreased approximately 20 percent, up to about 60 percent forest cover.

Reduced incidence of combined sewer overflow (CSOs). Many municipalities with older sewer systems have CSOs. When cities were developed before the mid-1900s, sanitary wastewater and stormwater were conveyed together to a receiving water. With the advent of treatment requirements for sanitary wastewater, those combined sewers were just connected to wastewater treatment plants. Therefore, the stormwater drainage in many older cities is conveyed to wastewater treatment plants, and during large storm events, it exceeds the plant capacity and overflows the raw sewage/stormwater mix into waterways. Solutions to CSOs have focused on sewer separation and detention in large tunnels—very expensive alternatives. LID techniques, by retaining and infiltrating runoff, reduce the frequency and amount of CSOs. For the past several years, communities such as Portland (Oregon), Chicago, and the District of Columbia have been piloting and implementing LID approaches aimed at reducing runoff generated and subsequently discharged into the combined system.

Habitat improvements. Innovative stormwater management techniques like LID or conservation design can be used to improve natural resources and wildlife habitat, or avoid expensive mitigation costs. For example, in 2008 the National Marine Fisheries Service (NMFS) determined that the National Flood Insurance Program (NFIP) administered by the Federal Emergency Management Agency (FEMA), jeopardized endangered salmon and killer whale populations by enabling development in environmentally sensitive floodplains. NMFS then proposed alternative measures FEMA could take to comply with the Endangered Species Act (ESA) and the goals of the NFIP. Such measures included additional protections for sensitive areas and requiring LID techniques in developments (National Wildlife Federation 2008; http://online.nwf.org/site/DocServer/Memo_to_Colleagues_re_NMFS_NFIP_Biop.pdf?docID=10562). The complete National Oceanic and Atmospheric Administration (NOAA) NMFS biological opinion is at http://www.nwr.noaa.gov/. Another example is the Etowah Habitat Conservation Plan (HCP) adopted by several local governments in Georgia's Etowah Basin, which includes adoption of LID techniques by participating local governments to streamline compliance with the ESA (www.etowahhcp.org/).

Reduced downstream flooding and property damage. LID practices, when applied throughout a watershed, can reduce flash flooding, and reduce property damage or risk during small storm events.

Reduce erosion and sediment loss. Designs that manage runoff on-site or as close as possible to its point of generation reduce erosion and sediment transport, as well as stream erosion.

Real estate value/property tax revenue. Property owners will pay a premium to be near amenities like water features, open space, trails, and clustered subdivisions. EPA's early *Economic Benefits of Runoff Controls* (USEPA 1995) described many examples. Indication of increased value of conservation subdivisions is observed by Rayman (2006), and for protected riparian corridors by Qui et al. (2006). The extent of willingness to pay for such an environment lies with the consumer because there have been observations where the added value was not observed (Kopits et al. 2007). As continuing urbanization makes natural areas more scarce and precious, and as more of the population moves into cities for reasons such as transportation, the characteristic of valuing green amenities should continue to be assessed to ensure that it is captured in cost/benefit analyses.

Lot yield. In cases where LID practices are incorporated on individual house lots and along roadsides as part of the landscaping, land that would normally be dedicated for a stormwater pond or other large structural control can be developed with additional housing lots.

Aesthetic value. LID designs can enhance a property's aesthetics using trees, shrubs, and flowering plants that complement other landscaping features, resulting in a perceived value of *extra* landscaping.

Quality of life, public health, and public participation. An increasing number of studies suggest that vegetation and green space—two key components of green infrastructure—can have a positive effect on human health. Recent research has linked the presence of trees, plants, and green space to reduced levels of inner-city crime and violence, a stronger sense of community, improved academic performance, and even reductions in the symptoms associated with attention deficit and hyperactivity disorders and other health aspects. More information on those types of studies is at the University of Illinois at Urbana-Champaign, Landscape and Human Health Laboratory, Human Health Benefits of Natural Landscapes Web site at http://lhhl.illinois.edu/all.scientific.articles.htm. Placing water quality practices on individual lots provides opportunities to enhance public awareness of their natural environment. Homeowners often consider natural open space to be important in planned communities.

Reduce air pollution through uptake by trees. Trees remove gaseous air pollution primarily by uptake via leaf stomata, though some gases are removed by the plant surface (Smith 1990). In 1994 the U.S. Forest Service estimated that trees in Baltimore removed an estimated 499 metric tons of air pollution at an estimated value to society of $2.7 million (Nowak and Crane 2000).

Reducing urban heat island effect through evapotranspiration. For trees in grass-covered areas, mid-day temperatures have been reported to be 0.7 degree Celsius (°C) to 1.3 °C cooler than in an open area. Reduced air temperature can improve air quality because the emission of many pollutants or ozone-forming chemicals are temperature dependent. Lower air temperature can reduce ozone formation (Souch and Souch 1993; Nowak at www.ufore.org)

Reduced energy costs for heating and cooling. Improved insulation against summer heat is provided with green roofs. Mature, shady, deciduous trees can reduce air conditioning costs up to 30 percent, while a wind break of evergreens can save 10–50 percent off heating costs in the winter (www.dnr.state.md.us/forests/publications/urban5.html). Green roofs are also cited to reduce urban heat island effect and provide winter insulation (Portland BES 2007).

Saving money on drainage infrastructure. Curb, gutter, storm drain pipes, and runoff detention practices can be reduced by reducing the volume of runoff to be conveyed (WERF 2008; USEPA 2007).

Example Green Infrastructure Benefits Analysis. An example of the wide array of benefits achievable is presented in Philadelphia's *Green City, Clean Water* report (2009) summarizing the vision of using LID to mitigate stormwater overflows. Philadelphia has, like many older cities, a legacy of combined sanitary and storm sewers, and recently compared the costs and benefits of using green infrastructure to help mitigate the CSOs to the costs of conventional stormwater retrofits such as tunnels. Table 3-1 presents an overview of the types of benefits the city envisions from a plan to implement green stormwater management.

The cost estimates for construction and maintenance can be found in the Long-Term Control Plan at http://www.phillywatersheds.org/ltcpu/. Additional information on valuing benefits and on the estimated capital and O&M costs of individual green infrastructure elements considered by Philadelphia are provided in Section 2 of this chapter.

A broad overview of the ancillary benefits that can be realized from LID is provided by the Center for Neighborhood Technology in its Green Values Calculator (www.cnt.org/natural-resources/green-values).

Table 3-1. Projected ancillary benefits of using LID and green infrastructure stormwater practices in Philadelphia to help achieve CSO mitigation

Economic Benefits	About 250 people would be employed in green jobs per year
Social Benefits	Increase of more than 1 million recreational user-days per year would be enjoyed
	Reduction of approximately 140 fatalities cause by excessive heat over the next 40 years
	Increase in property values of 2%–5% in greened neighborhoods
Environmental Benefits	1.5 billion pounds of carbon dioxide emissions avoided [partially through reduced heavy equipment requirements for alternative stormwater management] or absorbed
	Air quality benefits on average leading annually to 1-2 avoided premature deaths, 20 avoided asthma attacks, and 250 missed days of work or school
	Water quality and habitat improvements including 5-8 billion gallons of CSO avoided per year; 190 acres of wetlands restored or created, 11 miles of stream restored.
	Reduction in electricity and fuel use [partially through reduced construction of alternative stormwater management infrastructure].

Source: Green City, Clean Waters: Philadelphia's Program for Combined Sewer Overflow Control, A Long-Term Control Plan Update, Summary Report, 2009. http://planphilly.com/node/9842

1.2 Overview of the Urban Runoff Chapter

This chapter provides recommendations for restoring or maintaining predevelopment hydrology for urban runoff to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.

Maintaining or restoring predevelopment hydrology is the stormwater management goal recommended in this document, as required by Congress in section 438 of EISA for federal development and redevelopment projects exceeding 5,000 square feet. A number of technical resources, guidance, and design manuals are available that review in detail the key techniques and topics pertinent to urban runoff control. The technical material that is available in the referenced existing sources will not be repeated here.

1.2.1 Management Practices and Management Practice Scales

The following presents an overview of the approach presented in this chapter to achieve this goal by implementing strategies at the regional and watershed scale down to the site scale:

- At the regional or watershed scale, planning techniques such as smart growth and policies to allow conservation development, as part of watershed planning, can be used to lay the groundwork for ensuring that development has minimum impacts on water resources, including no net increase in stormwater runoff. This is important for both developed areas and for yet undeveloped areas.
- At the site scale, using green infrastructure/LID practices, along with source control and pollution prevention, are necessary to achieve the goals of protecting and restoring the Chesapeake Bay.

Applying LID practices at the site scale is recommended for new development, redevelopment, and retrofit. LID practices are flexible in design, so are widely applicable. LID practices such as functional conservation landscaping, bioretention, and swales require only a minimum modification from traditional landscaping design, often at no additional cost, and potentially provide long-term reductions in cost because of the reduced structural components requiring maintenance. There might also be reduced watering costs (because runoff is infiltrated instead of directed to drains) and turf care costs. In highly impervious urban areas where infiltration into soils is not feasible, the traditional stormwater management approach might call for detention of certain storm depth in a tank for water quality volume settling or peak shaving; that might not be significantly different in capital cost from retention in a cistern for use in landscaping or toilet flushing, and both require O&M. Appropriate practices are site-specific, as are costs. The basis for cost comparison, i.e., the alternative management strategy, is important in determining the extent of additional costs incurred with LID practices.

LID practices such as minimizing impervious surfaces, permeable pavement, green alleys, green streets, cisterns and rain barrels, and green roofs have become widely accepted in cities that have needed to manage excess pollutant runoff, water shortages, or flash flooding. The technology is now well-proven and shown to be adaptable for implementation at new development, redevelopment, and retrofit sites. Relatively small-scale LID practices can be dispersed throughout a site, capturing runoff from small drainage areas for infiltration, evapotranspiration, or capture and use. A site can be designed based on a *rooftop-to-stream* treatment train approach that includes both source-control practices and runoff treatment practices. The treatment train approach allows site designers and stormwater managers to take advantage of every opportunity to prevent runoff pollution and reduce runoff volume close to its source, thereby protecting headwater streams, municipal drainage systems, and downstream receiving waters, as follows:

- Minimize runoff generation by limiting the amount of directly connected impervious surface
- Capture runoff for evaporation or reuse
- Naturally infiltrate and filter runoff through landscaped areas
- Direct surplus runoff to engineered practices such as bioretention and other infiltration devices
- Prevent contamination of runoff using pollution prevention techniques
- Manage off-site runoff using regional stormwater practices, if necessary

This guidance provides an overview of the implementation measures recommended for managing urban stormwater to protect and restore the Chesapeake Bay or other waters affected by development. The implementation measures are action-oriented and, when considered together, from watershed scale to site scale, form a step-wise approach to addressing runoff volume and pollutant concentrations and for selecting management practices.

Sections 2 and 3 of this chapter summarize key elements of this approach: volume reduction and pollutant reduction through source control and treatment. Section 2 also addresses sectors of development such as new development and transportation-related development and provides references for more detailed information.

Section 4 addresses the opportunities to achieve volume reduction and pollutant reduction in the context of redevelopments. Section 5 addresses turf management. Particularly with respect to nutrients, that constitutes one of the most widespread land uses in the Chesapeake Bay watershed.

Appendix 1 consists of a series of fact sheets that briefly describe some of the key practices for which new research and guidance are available and include applicability, unit processes, feasibility constraints and limitations, runoff volume and pollutant-load-removal estimates as applicable, design and maintenance considerations, costs and factors that affect cost, and key references and resources. Photos and diagrams of typical applications are also provided. The fact sheets are intended to highlight new research and seminal resources with the most up-to-date approach on each management practice. Those practices that are adequately covered by other publicly available resources have links to existing sources.

1.2.2 Implementation Measures for Urban Runoff in the Chesapeake Bay Watershed to Control Nonpoint Source Nutrient and Sediment Pollution

Development or redevelopment projects with a footprint that exceeds 5,000 square feet should use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the watershed and site with regard to the temperature, rate, volume, and duration of flow. (Note: That is based on the approach adopted by Congress for federal facilities in section 438 of the Energy Independence and Security Act, 2007)

Implementation Measures:

U-1. Maximize infiltration, evapotranspiration, and harvest and use practices on-site, to the maximum extent technically feasible. Examples of these practices include the following:

- Bioretention cells or raingardens
- Green streets, right-of-way and parking lot designs and retrofits
- Cisterns and interior and exterior use of runoff
- Green roofs
- Tree planting and urban forestry
- Soil amendments and turf management

U-2. Implement policies to preserve or restore predevelopment hydrology with regard to the temperature, rate, volume and duration of flow, or more restrictive if needed for site-specific water quality protection. Implement at the regional, watershed, and site scales, as appropriate. Consider the following factors: land use, hydrology, geomorphology, and climate. Use Options 1 or 2 or similar performance-based approaches to achieve the desired hydrological goals:

- Option 1: Retain the 95th Percentile Rainfall Event (simplified method)
- Option 2: Conduct site-specific hydrologic analysis

U-3. Use planning and development techniques to direct development to areas where development will

- Have fewer impacts on water quality
- Preserve the integrity of healthy watersheds
- Achieve local objectives for infrastructure management and sustainability

U-4. Use conservation design and LID techniques to

- Minimize the hydrologic impacts of the development and preserve natural drainage ways to the extent feasible
- Integrate green infrastructure (GI)/LID practices into the design and construction of the development, to the extent feasible and preferably at the neighborhood scale

U-5. Examine federal facilities planning guidance, design manuals, and policies (municipalities would examine codes and ordinance, and industry or other facilities would examine corporate policy directives and guidance) for opportunities to revise and update

- Street standards and road design guidelines
- Parking requirements
- Setbacks (requirements for long driveways, and the like)
- Height limitations (encourage density where appropriate)
- Open space or natural resource plans
- Comprehensive plans or facility master plans

U-6. Examine and revise transportation, right-of-way and parking lot policies, guidance, and standards to reduce impervious areas and water resource impacts.

U-7. Minimize directly connected impervious areas in new development, redevelopment, and in retrofits by

- Disconnection of downspouts
- Infiltration of runoff onsite (preferably through bioretention practices)
- Product substitution, e.g., use of permeable paving materials
- Harvest and use of runoff onsite
- Construction of green roofs

U-8. Restore streams, floodways, and riparian areas to mitigate channel erosion and sedimentation and enhance the pollutant removal capacity of these areas.

U-9. Reduce the impacts of existing impervious areas through redevelopment and infill policies and strategies and identify and implement incentives for redevelopment that encourage the use of GI/LID designs and practices

- Retrofit existing urban areas to achieve the desired performance goals
- Assess candidate sites, prioritize, and implement practices based on expected cumulative benefit to the subwatershed or watershed
- Assess retrofit potential of significant runoff sources such as streets, highways, parking lots, and rooftops.
- Develop and implement redevelopment programs that identify opportunities for a range of types and sizes of redevelopment projects to mitigate water resource impacts that
  - Establish appropriate redevelopment stormwater performance standards consistent with the goal of restoring predevelopment hydrology with regard to the temperature, rate, volume and duration of flow, or more restrictive if needed for site-specific water quality protection, as determined by the appropriate regulatory authority for the region or site
  - Include development of an inventory of appropriate mitigation practices (e.g., permeable pavement, infiltration practices, green roofs) that will be encouraged or required for implementation at redevelopment sites that are smaller than the applicability threshold
  - Include site assessment to determine appropriate GI/LID practices
  - Review facility planning documents and specifications (as well as any applicable codes and ordinances) and modify as appropriate to allow and encourage GI/LID practices
  - Implement GI/LID demonstration projects
  - Incentivize early adopters of GI/LID practices
  - Maximize urban forest canopy to reduce runoff
  - Conduct soil analyses and amend compacted urban soils to promote infiltration

Reduce Pollutant Concentrations by implementing source control measures and treatment practices as necessary to meet water quality goals

Source Control/Pollution Prevention

Implementation Measures:

U-10. Identify the pollutants of concern (POCs) to help target the selection of pollution prevention/source control that are most appropriate, for example, nutrients and sediment.

U-11. Implement pollution prevention/source control practices, i.e., nonstructural, programmatic efforts as basic, routine land management practices to target specific pollutants.

U-12. Require source controls on

- New and redevelopment site plans for commercial/industrial facilities
- Commercial/industrial facilities through development of a
  - Stormwater Pollution Prevention Plan (SWPPP) where required for regulated industrial categories
  - Similar stormwater pollution prevention plans that might be required by local authorities
- Municipal facilities or other designated Municipal Separate Storm Sewer System (MS4s) permittees through development of Pollution Prevention/Good Housekeeping programs such as the Stormwater Phase II Minimum Control Measures.

U-13. Develop and implement ongoing outreach programs aimed at behavior change to prevent pollution and control it at its source. Methods for impact and effectiveness evaluation should be incorporated into these outreach and education programs.

U-14. Implement programs for disconnection of directly connected impervious areas, such as residential downspout disconnection programs.

U-15. Conduct inspections of commercial/industrial facilities to provide compliance assistance or to ensure implementation of controls.

Runoff Treatment

Implementation Measures:

U-16. Identify the POCs to help target the type of treatment approaches that are most appropriate.

U-17. Select treatment practices based on applicability to the POCs

- Use practices to reduce runoff volume as the preferred and most reliable approach to reducing pollutant loading to receiving waters
- Use treatment practices as needed if reduction of runoff is not feasible
- Base the selection of treatment practice on
  - Treatment effectiveness for the POC to ensure discharge quality
  - Long-term maintenance considerations to ensure continued adequate maintenance and recognition of life-cycle costs
  - Site limitations to ensure appropriateness of practice to the site
  - Aesthetics and safety to ensure public acceptance

Turf Management Implementation Measures

Implementation Measures:

Turf Landscape Planning and Design

U-18. Where turf use is *essential* and appropriate, turf areas should be designed to maintain or restore the natural hydrologic functions of the site and promote sheet flow, disconnection of impervious areas, infiltration, and evapotranspiration.

Turf Management

U-19. Use management approaches and practices to reduce runoff of pollutant loadings into surface and ground waters.

U-20. Manage turf to reduce runoff by increasing the infiltrative and water retention capacity of the landscape to appropriate levels to prevent pollutant discharges and erosion.

U-21. Manage applications of nutrients to minimize runoff of nutrients into surface and ground waters and to promote healthy turf

- Where appropriate, consider modifications to operations, procedures, contract specifications and other relevant purchasing orders, and facility management guidance to reduce or eliminate the use of fertilizers containing P

U-22. Manage turf and other vegetated areas to maximize sediment and nutrient retention.

U-23. Reduce total turf area that is maintained under high input management programs that is not essential for heavy use situations, e.g., sports fields and heavily trafficked areas.

U-24. Convert *nonessential*, high-input turf to low-input or lower maintenance turf or vegetated areas that require little or no inputs and provide equal or improved protection of water quality.

U-25. Use turf species that reduce the need for chemical maintenance and watering, and encourage infiltration through deep root development.

U-26. Conduct a facility or municipal wide assessment of the landscaped area within the facility property or jurisdiction. This assessment should include

- A map of the jurisdiction or facility, including the identification of all turf and other landscape areas
- An inventory or calculation of the total turf and other landscape area in acres or hectares using GIS techniques or other methods
- An evaluation to determine essential and nonessential turf areas
- Identification and delineation of all high-input, low-input, and no-input turf areas
- An evaluation of turf management activities and inputs, preferably by turf category or significant turf area within the facility or jurisdiction
- An assessment of landscape cover type benefits such as pollution load reductions and resource savings, e.g., water and energy that are provided by each landscape cover type
- An assessment of landscape cover type health, infiltrative and pollutant loading capacity and opportunities to increase soil health to promote the infiltrative capacity of turf and landscape areas
- An assessment of surface water and groundwater loadings related to high-input, low-input, and no-input turf area

U-27. Develop a management plan that contains

- An analysis of options to reduce or eliminate *nonessential* turf or convert *essential* turf to low-input turf that performs optimally from a water resource protection perspective
- An analysis of turf areas to identify opportunities to maximize water quality benefits of landscapes in regard to runoff, in-stream flows, infiltration, groundwater recharge and sediment, nutrient and pathogen loadings
- A landscaping approach that integrates turf management within the context of natural resource and habitat plans
- Stated goals and objectives regarding the reduction of turf related inputs (water, fertilizers, pesticides, fossil fuels) and maximizing water resource benefits on a facility- or municipality-wide basis
- An analysis of options to reduce potable water use by using cultural practices, hardy cultivars, or recycled water or harvested runoff
- An identification of areas where soil amendments can be used to enhance soil health and the infiltration capacity of the soils
- Areas of turf that could be used to manage runoff
- Areas of turf that could be replaced by lower maintenance cultivars or other grasses such as switch grass
- A training program for landscaping personnel
- An implementation schedule
- An annual landscaping inventory and progress report

U-28. Develop and implement ongoing public education and outreach programs Bay-friendly lawn, landscape, and turf management. Programs should target behavior change and promote the adoption of water quality friendly practices by increasing awareness, promoting appropriate behaviors and actions, providing training and incentives. Impact and effectiveness evaluation should be incorporated into such outreach and education programs.

2 Implementation Measures for Reducing Urban Runoff Volume

The shortcomings of traditional, detention-based stormwater control efforts, and the need to use approaches to reduce runoff volume to protect water quality, have been well-documented (NRC 2008; USEPA 2009).

This section presents an approach of land use and growth management measures that guide development to areas that minimize effects on sensitive resources and open space, and ensure that new and redevelopment sites are designed to reduce runoff volume through on-site stormwater retention.

Development or redevelopment projects with a footprint that exceeds 5,000 square feet should use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the watershed and site with regard to the temperature, rate, volume, and duration of flow. (Note: Based on the approach adopted by Congress for federal facilities in Section 438 of the Energy Independence and Security Act, 2007)

Implementation Measures:

U-1. Maximize infiltration, evapotranspiration, and harvest and use practices on-site, to the maximum extent technically feasible. Examples of these practices include

- Bioretention cells or raingardens
- Green streets, right of way and parking lot designs and retrofits
- Cisterns and interior and exterior use of runoff
- Green roofs
- Tree planting and urban forestry
- Soil amendments and turf management

U-2. Implement policies to preserve or restore predevelopment hydrology with regard to the temperature, rate, volume and duration of flow, or more restrictive if needed for site-specific water quality protection. Implement at the regional, watershed, and site scales, as appropriate. Consider the following factors: land use, hydrology, geomorphology, and climate. Use

Options 1 or 2 or similar performance-based approaches to achieve the desired hydrological goals:

- Option 1: Retain the 95th Percentile Rainfall Event (simplified method)
- Option 2: Conduct site-specific hydrologic analysis

U-3. Use planning and development techniques to direct development to areas where development will

- Have fewer impacts on water quality
- Preserve the integrity of healthy watersheds
- Achieve local objectives for infrastructure management and sustainability

U-4. Use conservation design and LID techniques to

- Minimize the hydrologic impacts of the development and preserve natural drainageways to the extent feasible
- Integrate green infrastructure (GI) LID practices into the design and construction of the development, to the extent feasible and preferably at the neighborhood scale

U-5. Examine federal facilities planning guidance, design manuals, and policies (municipalities would examine codes and ordinance, and industry or other facilities would examine corporate policy directives and guidance) for opportunities to revise and update

- Street standards and road design guidelines
- Parking requirements
- Setbacks (requirements for long driveways, etc.)
- Height limitations (encourage density where appropriate)
- Open space or natural resource plans
- Comprehensive plans or facility master plans

U-6. Examine and revise transportation, right-of-way, and parking lot policies, guidance and standards to reduce impervious areas and water resource impacts.

U-7. Minimize directly connected impervious areas in new development, redevelopment, and retrofit by

- Disconnection of downspouts
- Infiltration of runoff onsite (preferably through bioretention practices)
- Product substitution, e.g., use of permeable paving materials
- Harvest and use of runoff onsite
- Construction of green roofs

U-8. Restore streams, floodways, and riparian areas to mitigate channel erosion and sedimentation and enhance the pollutant removal capacity of these areas.

U-9. Reduce the impacts of existing impervious areas through redevelopment and infill policies and strategies and identify and implement incentives for redevelopment that encourage the use of GI/LID designs and practices.

- Retrofit existing urban areas to achieve the desired performance goals
- Assess candidate sites, prioritize, and implement practices based on expected cumulative benefit to the subwatershed or watershed
- Assess retrofit potential of significant runoff sources such as streets, highways, parking lots, and rooftops
- Develop and implement redevelopment programs that identify opportunities for a range of types and sizes of redevelopment projects to mitigate water resource impacts that
  - Establish appropriate redevelopment stormwater performance standards consistent with the goal of restoring predevelopment hydrology with regard to the temperature, rate, volume and duration of flow, or more restrictive if needed for site-specific water quality protection, as determined by the appropriate regulatory authority for the region or site
  - Include development of an inventory of appropriate mitigation practices (e.g. permeable pavement, infiltration practices, green roofs) that will be encouraged or required for implementation at redevelopment sites that are smaller than the applicability threshold
  - Include site assessment to determine appropriate GI/LID practices
  - Review facility plans and specifications (as well as any applicable codes and ordinances) and modify as appropriate to allow and encourage GI/LID practices

- Implement GI/LID demonstration projects
- Incentivize early adopters of GI/LID practices
- Maximize urban forest canopy to reduce runoff
- Conduct soil analyses and amend compacted urban soils to promote infiltration

2.1 Maximize Infiltration, Evapotranspiration, and Harvest and Use

Restoring or maintaining predevelopment hydrology has emerged as the generally preferred approach for controlling urban runoff and protecting water quality for several reasons. Most importantly, this approach addresses the root cause of impairment. Traditional control approaches attempt to control the symptoms (e.g., peak flow, excess pollutants), but that is largely ineffectual in protecting streams and water quality because of the scale of the problem, the cumulative effects of multiple developments, and the need to manage both site- and watershed-level effects. The problems associated with traditional control approaches in protecting water quality are presented in the Introduction to this chapter. This section presents the approaches for obtaining the goal of restoring or maintaining predevelopment hydrology.

To maintain or restore site or watershed hydrology, the watershed should function hydrologically after development as it did before human induced land alterations. In the Chesapeake Bay, most areas before development were forested with mature trees, and the bulk of the rainfall was intercepted, infiltrated, or evapotranspired.

To mimic the natural behavior of the landscape, the stormwater management system should be designed to manage runoff through the following:

- Infiltration and groundwater recharge
- Evapotranspiration
- Harvest rainfall and use of captured rainfall on-site

On sites where inadequate area or the intended use of the development precludes managing the desired volume on-site, off-site mitigation should be considered within the same subwatershed.

2.2 Implement Policies to Preserve and Restore Predevelopment Hydrology

This guidance provides two options that site designers can use to establish appropriate performance goals to maintaining or restoring predevelopment hydrology; however, note that in many situations, it might be feasible and beneficial to have no runoff from a site. The discussion of the two options does not preclude the use of more protective performance goals. Option 1, the methodology based on retention of the 95th percentile rainfall event, is a simple way to establish the performance goal and does not require detailed analysis of the site conditions or a continuous simulation modeling approach. It is assumed that using that performance standard will generally result in designs that protect or restore site hydrology. However, there could be situations where Option 1 (retaining the 95th percentile rainfall event) is not protective enough to maintain or restore the predevelopment hydrology of the project (for example, in some headwater streams) or is overprotective (in the case of naturally impermeable surfaces). In such cases, Option 2 (site-specific hydrologic analysis) could be used to determine the performance design objective necessary to preserve predevelopment runoff conditions. The expectation is that Option 2 can be used in situations where the designer has the requisite data and resources to analyze site infiltration, evapotranspiration, interception, and potential harvest and use scenarios to establish these design objectives and to design the runoff management system to meet the goals of maintaining and restoring site hydrology. More detailed descriptions of the two options follow.

Option 1: Retain the 95th Percentile Rainfall Event

Under Option 1, managers design, construct, and maintain stormwater management practices that manage rainfall on-site, and prevent the off-site discharge of the precipitation from all rainfall events less than or equal to the 95th percentile rainfall event to the Maximum Extent Technically Feasible (METF). The 95th percentile rainfall event is the event whose precipitation total is greater than or equal to 95 percent of all storm events over a given period of record. For example, to determine what the 95th percentile storm event is in a specific location, all 24-hour storms that have recorded values over a 30-year period would be tabulated, and a 95th percentile storm would be determined from that record, i.e., 5 percent of the storms would be greater than the number determined to be the 95th percentile storm. Thus the 95th percentile storm would be represented by a number such as 1.5 inches, and that would be the design storm. The designer selects a system of practices, to the METF, that infiltrate, evapotranspire, or harvest and reuse that volume multiplied by the total area of the facility/project footprint. Methods and data used to estimate the 95th percentile event are discussed in Appendix 2 of this chapter.

For the purposes of this document, retaining all storms up to and including the 95th percentile storm event is analogous to maintaining or restoring the predevelopment hydrology with respect to the volume, flow rate, duration, and temperature of the runoff for most sites.

Where technically feasible, the goal of Option 1 is that 100 percent of the volume of water from storms less than or equal to the 95th percentile event over the footprint of the project should not be discharged to surface waters. In some cases, runoff can be harvested and used and ultimately can be discharged to surface waters or a sanitary treatment system; such direct or indirect discharges must be authorized. For example if runoff is captured for nonpotable uses such as toilet flushing or other uses that are not irrigation related, the waters could be discharged into the sanitary sewer system or other appropriate system depending on local requirements.

Runoff volumes that exceed the 95th percentile event can be managed by using overflow or diversion strategies and practices as well as the detention practices used for flood control.

Designers should also account for potential thermal effects of structures such as roofs and paved surfaces that can increase the temperature of stormwater runoff. Designers should select materials that minimize temperature increases (consider material such as concrete versus asphalt; vegetated roofs, and the like and use them as appropriate).

Rationale for Selecting Option 1. Retention of 100 percent of all rainfall events equal to or less than the 95th percentile rainfall event was estimated to be a representation of the natural hydrology on most sites as a default value. On most sites, little or no runoff occurs from small, frequently occurring storms, and such storms account for a large proportion of the annual precipitation volume. When development occurs, the hydrologic balance of the site is disturbed and as a result runoff occurs from both small and large storms. There is an increase in the number of runoff events, and an increase in the runoff volume, duration, rate, and temperature. Receiving water degradation and habitat loss occur from this changed hydrologic regime.

Table 3-2. Example 95th percentile storm events or select U.S. cities

City	95th percentile event rainfall total (in)
Baltimore, MD	1.6
Binghamton, NY	1.2
Charleston, WV	1.2
Elmira, NY	1.2
Harrisburg, PA	1.4
Lynchburg, VA	1.5
Norfolk, VA	1.7
Richmond, VA	1.7
Salisbury, MD	1.7
Washington, DC	1.5
Williamsburg, VA	1.4

Source: Adapted from Hirschman and Kosco 2008

Table 3-2 contains representative 95th percentile storm event volumes in inches from selected cities in the Chesapeake Bay watershed. Figure 3-10 contains a plot representing storm event frequency for Washington, DC. In Figure 3-10, the 95th percentile storm event has been identified and is approximately 1.5 inches.

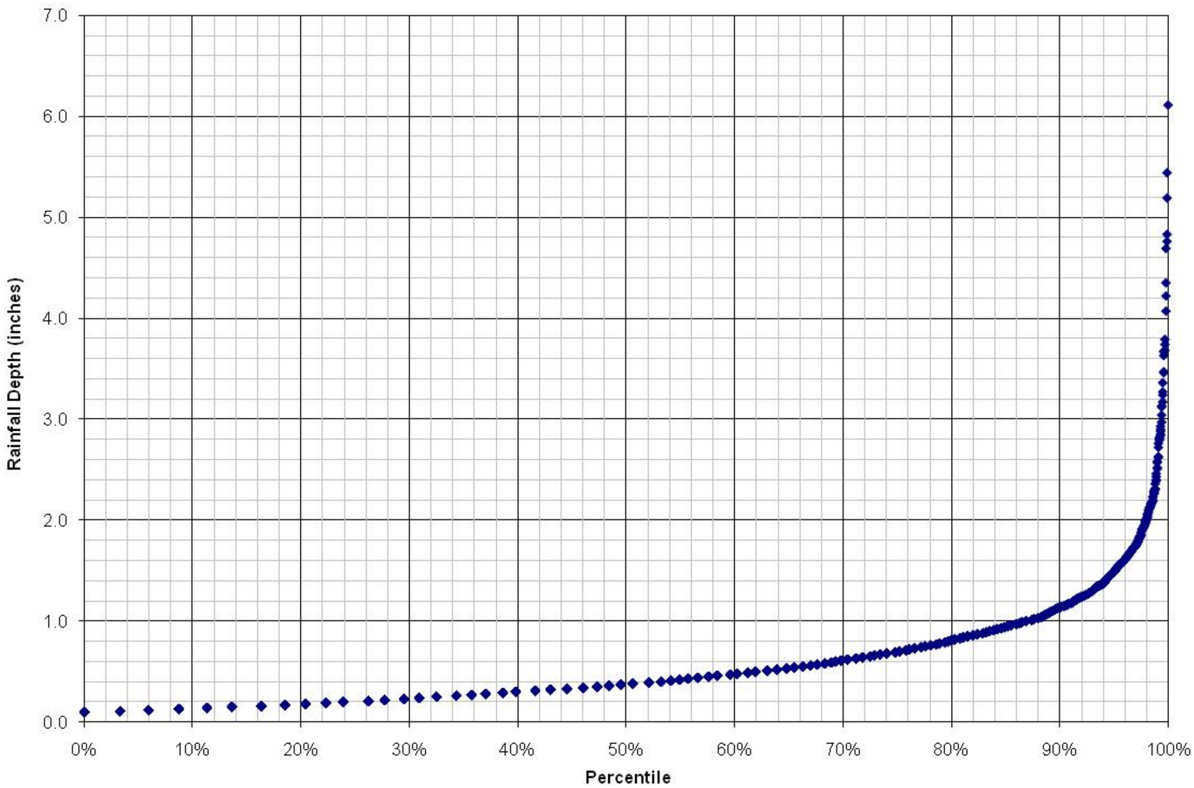


Figure 3-10. Rainfall frequency spectrum showing the 95th percentile rainfall event for Washington, DC (Reagan National Airport ~1.5 inches).

Calculating the 95th Percentile Rainfall Event

This chapter's Appendix 3 contains information on how to calculate the 95th percentile rainfall event for a specific area. A long-term record of daily rainfall amounts (such as 30 years) is needed to calculate long-term precipitation values (Chang 1977; Boughton 2005). When selecting the length of record to use, consider the potential effects of climate change in the region—for example, has the rainfall pattern changed over the past few decades, and if so, should a safety factor be included in case the trend continues?

Designers opting to use Option 1 would need to do the following:

1. Calculate or verify the precipitation amount from the 95th percentile storm event (that number would be typically expressed in inches, e.g., 1.5 inches)

2. Employ on-site stormwater management controls to the METF that infiltrate, evapotranspire, or harvest and use the appropriate design volume

- The 95th percentile event can be calculated by using the following procedures below (summarized from Hirschman and Kosco. 2008. *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program,* Center for Watershed Protection): Obtain a long-term rainfall record from a nearby weather station (daily precipitation is fine, but try to obtain at least 30 years of daily record). Long-term rainfall records can be obtained from many sources, including NOAA at www.nesdis.noaa.gov

- Remove from the data set all data for small rainfall events that are 0.1 inch or less and snowfall events that do not immediately melt. Such events should be deleted because they do not typically cause runoff and could cause the analyses of the 95th percentile storm runoff volume to be inaccurate.

- Use a spreadsheet or simple statistical package to sort the rainfall events from highest to lowest. In the next column, calculate the percentage of rainfall events that are less than each ranked event (event number / total number of events). For example, if there were 1,000 rainfall events and the highest rainfall event was a 4-inch event, 999 events are less than the 4-inch rainfall event (or a percentile of 999 / 1,000, or 99.9 percent).

- Use the rainfall event at 95 percent as the 95th percentile storm event.

Option 2: Site-Specific Hydrologic Analysis

Under Option 2, the predevelopment hydrology would be determined on the basis of site-specific conditions and local meteorology by using continuous simulation modeling techniques, published data, studies, or other established tools. The designer would then identify the predevelopment condition of the site and quantify that the post-development runoff volume and peak flow discharges are equivalent to predevelopment conditions. The post-construction rate, volume, duration and temperature of runoff should not exceed the predevelopment conditions, and the predevelopment hydrology should be replicated through site design and other appropriate practices to the METF. Additional discussions of appropriate methodologies to use in assessing site hydrology have been included in Appendix 3.

The predevelopment hydrologic condition of the site is the combination of runoff, infiltration, and evapotranspiration rates and volumes that typically existed on the facility site before *development* on a greenfields site (meaning any construction of infrastructure on undeveloped land such as meadows or forests). In practice, determining the predevelopment hydrology of a site can be difficult if no suitable reference site is available. As a result, reference conditions for typical land cover types in the locality often are used to approximate what fraction of the precipitation ran off, soaked into the ground, or was evaporated from the landscape. Using reference conditions can be problematic if suitable data are not available or unique site conditions exist that do not fit within a typical land use cover type for the area, e.g., meadow or forest. The intent is not to restore the site to pre-Columbian conditions but to develop or redevelop the site to ensure that a stable hydrologic regime is in place to protect groundwater, surface water, and receiving stream channel stability.

For redevelopment sites, existing site conditions and uses of the site can influence the amount of runoff that can be managed on-site through infiltration, evapotranspiration, and harvest and use and, thus, affect the achievement of the performance design objective. In the context of some redevelopment projects, fully restoring predevelopment hydrology can be difficult to achieve. In such cases, EPA recommends using a systematic analysis to determine what practices can be implemented. The *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act,* EPA 841-B-09-001 (USEPA 2009e), (http://www.epa.gov/owow/nps/lid/section438) provides methodology for federal facilities in determining METF. Examples of conditions that could prevent a fully restored predevelopment hydrology are a combination of the following:

- The presence of shallow bedrock; contaminated soils, near-surface groundwater; or other factors such as underground facilities or utilities.
- The design of the site precludes the use of soil amendments, plantings of vegetation or other designs that can be used to infiltrate and evapotranspirate runoff.
- Water harvesting and reuse are not practical or possible because the volume of water used for irrigation, toilet flushing, industrial make-up water, wash-waters, and the like, is not significant enough to warrant designing and using water harvesting and reuse systems.
- Modifications to an existing building to manage stormwater are not feasible because of structural or plumbing constraints or other factors as identified by the facility owner/operator.
- Small project sites where the lot is too small to accommodate infiltration practices adequately sized to infiltrate the volume of runoff from impervious surfaces.
- Soils that cannot be sufficiently amended to provide for the requisite infiltration rates.
- Situations where site use is inconsistent with the capture and reuse of stormwater or other physical conditions on-site that preclude the use of plants for evapotranspiration or bioinfiltration.

- Retention or use of stormwater on-site or discharge of stormwater on-site via infiltration has a significant adverse effect on the site or the downgradient water balance of surface waters, groundwaters or receiving watershed ecological processes.
- State and local requirements or permit requirements that prohibit water collection or make it technically infeasible to use certain green infrastructure/LID techniques.
- Retention or use of stormwater on the site would cause an adverse water balance to either or both the receiving surface waterbody or groundwater.

In cases where a technical infeasibility exists that precludes full implementation of the performance design goal, the facility should still use stormwater practices to infiltrate, evapotranspire, or harvest and use on-site the maximum amount of stormwater technically feasible.

2.3 Land Use Planning and Development Techniques to Direct Development

2.3.1 Impacts of Land Use on Hydrology and Geomorphology

An evaluation of the land use and hydrology/geomorphology of a watershed or site is an important first step in designing to maintain or restore predevelopment hydrology and mitigate pollutant loading.

One of the key strategies to reduce runoff is to change the pattern of land development to one that is less destructive to water quality. Land use is the largest driver of changes in stormwater runoff, and developed and urbanized lands contribute the largest volumes of increased runoff. The progression of development has led to the increased urbanization of the population. The urbanization of land, however, has outpaced the urbanization of the population, indicative of *sprawl*-type development. That trend has been witnessed nationally, and with the population of the Chesapeake Bay area expected to continue to increase it will place more development pressure on the watershed (National Research Council 2008; Beck et al. 2003).

Such urbanization patterns have significant effects on land use as the predeveloped conditions of forests, meadows, and agricultural lands are replaced by hardened landscapes. Impervious surfaces, such as roads and roofs are the main land cover in urban areas and have a significant impact on stormwater quality. For example,

- Roads and parking lots are as much as 70 percent of total impervious cover in ultra-urban areas (National Research Council 2008)

- Roads tend to capture and export more stormwater pollutants than other land covers in highly impervious areas, especially for small rainfall events (National Research Council 2008)

Even urban land cover that is not hardscape does not infiltrate rainfall as it would before development. Urban soils have much higher bulk density (the mass of dry soil divided by its volume, which serves as a predictor of porosity) than undisturbed soils because of soil compaction typical of construction practices and urban uses. As shown in Table 3-3, the bulk density of urban soils is closer to concrete than to undisturbed soils. The ability of soils with such levels of compaction to infiltrate and retain stormwater is greatly diminished and results in greater quantities of runoff. The lack of an absorptive humus layer, and active soil biota, can also play a role in reducing infiltration rates.

As a result of such compaction, the runoff from urban soils often resembles that of impervious surfaces, especially for larger storm events.

Table 3-3. Bulk density of urban soils is closer to concrete than to undisturbed soils

Material	Bulk density (grams per cubic centimeter)
Undisturbed Soil	1.1 to 1.4
Urban Lawn	1.5 to 1.9
Fill Soil	1.8 to 2.0
Soil Adjacent to Buildings and Roadways	1.5 to 2.1
Concrete	2.2

Source: Schueler and Holland 2000

An understanding of such effects is essential to effectively mitigate them. Watershed and site assessments enable a better understanding of the factors contributing to hydromodification, so that appropriate mitigation techniques can be selected. The site assessment process should evaluate the hydrology, topography, soils, vegetation, and water features (i.e., wetlands, riparian areas, and floodplains) to identify how stormwater moves through the site before development. Additional information on the site assessment process is provided in Section 3 of this chapter.

In addition, to protect stream channels from increased erosion, it is necessary to control the total time—the duration—stream channels are subject to geomorphically significant flows. The flows can result in channel erosion caused by the additional energy imparted to the stream channel by the increases in runoff velocities and volumes. The extended high flows typically lead to stream channel destabilization because the stream did not evolve under those conditions and lacks the capacity to dissipate this increased energy without scouring the stream bed. In response, both the channel and banks are incised, creating increased sediment transport. Those problems are aggravated as the flow travels downstream, with other altered watersheds contributing their increased volumes.

The traditional stormwater management approach was based primarily on flood protection and often focused on not exceeding a predevelopment flow rate, but it did not take into account additional volume. When there is greater volume to be discharged, the duration of the peak flow rate is longer than under predevelopment condition. When multiple discharges of this type enter a receiving stream, the flow peaks that once were sequential become additive, creating much higher peak flows in the stream than existed in predevelopment conditions. The relationships between hydrologic and geomorphic changes and biological parameters can be analyzed using protocols such as that laid out in WERF's *Protocols for Studying Wet Weather Impacts and Urbanization Patterns* (WERF 2008a).

2.3.2 Appropriate Designs as Part of a Comprehensive Watershed Plan

This section contains an overview of example strategies, policies, and practices that land managers on different scales (federal, state, local) have used to reduce the effects of development and redevelopment on receiving water hydrology. The strategies and approaches used to achieve a community's hydrologic stormwater goals will depend on the scale at which the approach is to be applied—regional, local jurisdiction, watershed, subdivision/facility campus, or building lot. Issues and potential tools for different scales of implementation are provided in Table 3-4.

Such strategies should be included as part of a comprehensive watershed plan to protect the resources in the watershed and downstream. Development approaches should be viewed across a watershed or region, down to the local scale, to help achieve communities' desired goals for water resources while avoiding unintended consequences, such as flooding or inadequate base stream flow. Comprehensive planning is an effective nonstructural tool to reduce the amount of impervious surface in a watershed and to guide future development in a manner that best protects water quality.

Water management planning is just one component of watershed planning for restoring ecosystem function. For example, the importance of maintaining natural daylight/nighttime conditions for the propagation of many species has recently become recognized and integrated into facility planning (General Services Administration 2005) (P-100-2005-2.12 Landscape Lighting, http://docs.darksky.org/Codes/SimpleGuidelines.pdf). Comprehensive watershed planning should ideally encompass a holistic approach to sustainability.

Table 3-4. Strategies and tools for implementing stormwater protection goals at different scales

Scale	Example strategies at different scales	Example programs and initiatives
National	Water Environment Research Foundation	*Using Rainwater to Grow Livable Communities Sustainable Stormwater Best Management Practices (BMPs),* Case studies of LID program development in cities nationwide, tools and resources targeted to specific user groups.
	National Association of Regional Councils	Promotes information exchange to help regional organizations achieve goals.
	EPA's *Green Infrastructure* and *LID* websites, U.S. Department of Defense LID Policy	Provide national-level guidance
	NFIP under the FEMA	*NFIP and the Endangered Species Act: Implementing a salmon friendly program by developing a reasonable and prudent alternative;* Program to prepare guidance for use in developing flood-risk areas <http://www.fema.gov/about/regions/regionx/nfipesa.shtm>
Regional	Regional Commissions facilitate cooperation (such as similar ordinances for development equity) and leverage funds for outreach, etc.	Northern Virginia Regional Commission: Example program www.onlyrain.org. Washington Metropolitan Council of Governments: Example Symposium—Innovative Stormwater Controls on Roads & Highways, November 2009
	Interstate, multijurisdictional partnerships	Chesapeake Bay Program: state, federal, academic and nonprofit partnership. www.chesapeakebay.net/partnerorganizations.aspx
	Public-Private Partnerships (any scale)	The Healthy Lawn and Clean Water Initiative, Chesapeake Bay Executive Council and the fertilizer industry agree on voluntary P reductions in fertilizer http://archive.chesapeakebay.net/pubs/Lawn_Care_MOU.pdf *The Growing Home Campaign.* Provides incentives for homeowners to increase urban canopy with cost shared by landscape industry. www.baltimorecountymd.gov/Agencies/environment/growinghome
	University-Public-Private Partnerships	Designing and monitoring pilot or demonstration facilities. Outreach with university and extension programs. Stormwater programs at Villanova, University of Maryland, and North Carolina State University working together in partnership Connecticut's NEMO (Nonpoint Education for Municipal Officials) Program and Center for Land Use Education and Research (CLEAR), http://nemo.uconn.edu

Table 3-4. Strategies and tools for implementing stormwater protection goals at different scales *(continued)*

Scale	Example strategies at different scales	Example programs and initiatives
Local Jurisdiction	Ordinances that allow LID, fees to enable programs, fines, technical assistance	D.C.'s Impervious Area Fee Spotsylvania, Virginia, Ordinance Lycoming County, Pennsylvania (Draft), prepared under PA Act 167
	Smart Growth policies	Baltimore County, Maryland, designates land management areas; www.baltimorecountymd.gov/Agencies/planning/masterplanning/smartgrowth.html%20 The *Philadelphia Green* program revitalizes and maintain abandoned land and public spaces by partnering with government, businesses, and the community
	Green Street policies	The Port Towns' (Maryland) 2010 Legislative Priorities include *Fund at least one Green Street in each of the Port Towns.* http://porttowns.org
Watershed	Pollutant trading[a,b]	Region states are evaluating programs.[c] EPA Region 3 is evaluating the use of urban stormwater trading for the Chesapeake Bay. Virginia Soil and Water Conservation Board Guidance Document on Stormwater Nonpoint Nutrient Offsets, Approved July 23, 2009. http://townhall.virginia.gov/L/GDocs.cfm
	Use watershed-scale hydraulic and pollutant models to optimize control type and location	Models such as BMP-DSS (BMP Decision Support System) have been used in Maryland as planning tools
	Inter-jurisdictional cooperation for purposes of load management and TMDL application	Chesapeake Bay Program
	Local Watershed Groups where Volunteers lead projects	EPA's *Watershed Central* provides blog and information: http://wiki.epa.gov/watershed/index.php Anne Arundel County, Maryland Master Watershed Stewards Academy
	Fee-in-lieu or off-site mitigation when compliance on-site is not feasible	Washington, DC, Proposed Off-Site Stormwater Mitigation Fee
	Total Maximum Daily Load (TMDL) provides framework for prioritizing efforts	Restoring the Legendary Lynnhaven Oysters: *Coordinated Actions Lower Bacteria Levels and Reopen Shellfish Areas in the Lynnhaven River Watershed,* www.epa.gov/owow/TMDL/tmdlsatwork/pdf/lynnhaven_river_sound_byte.pdf; and www.epa.gov/owow/nps/Success319/state/va_3bays.htm

Table 3-4. Strategies and tools for implementing stormwater protection goals at different scales *(continued)*

Scale	Example strategies at different scales	Example programs and initiatives
Facility campus or subdivision	Smart Growth, Conservation Development	Downtown Silver Spring, Maryland Sussex County, Delaware Arlington, Virginia's MetroRail Corridor Lancaster County, Pennsylvania
	General Service Administration P-100 Guidance	U.S. Navy Police and Security Operations Facility, Norfolk, VA. *High Performance Federal Building Database,* http://femp.buildinggreen.com/
Building Lot	LID Practices	Design guides for LID prepared by federal, state, and, local entities

Notes

a. Lal, H. 2008. *Nutrient Credit Trading: A Market-based Approach for Improving Water Quality* NTSC/NRCS/USDA; www.wsi.nrcs.usda.gov/products/w2q/mkt_based/docs/nitrogen_credit_trading.pdf

b. USEPA. 2003b. *Fact Sheet: Water Quality Trading Policy*. www.epa.gov/owow/watershed/trading/2003factsheet.pdf; and USEPA 2003b. *Water Quality Trading Policy*, www.epa.gov/owow/watershed/trading/finalpolicy2003.pdf

c. Chesapeake Bay Foundation. No Date. *Facts about Nutrient Trading from the Chesapeake Bay Foundation,* www.cbf.org/Document.Doc?id=141

A watershed approach is a flexible framework for managing water resource quality and quantity within specified drainage areas, or watersheds. A watershed plan is a strategy that provides assessment and management information for a geographically defined watershed, including the analyses, actions, participants, and resources related to developing and implementing the plan. Typical steps in watershed plan development include the following:

- Characterize existing conditions
- Identify and prioritize problems
- Define management objectives and procedures for documenting outcomes compared to objectives
- Develop protection or remediation strategies
- Implement and adapt selected actions as necessary
- Document activities a watershed

The watershed approach includes stakeholder involvement and management actions supported by sound science and appropriate technology. Resources for preparing watershed plans are provided in Table 3-5.

The strategy selected for protecting and restoring watershed hydrology depends on the existing condition of the landscape: new development strategies have a different focus than retrofit activities in an existing urban landscape. Where redevelopment or infill development occurs, measures and practices to restore the predevelopment hydrology should be used, although a different suite of approaches might be more suitable than those recommended for new development.

Table 3-5. Resources for preparing watershed plans

Reference	Information provided
National Management Measures to Control Nonpoint Source Pollution from Urban Areas. EPA-841-B-05-004. (USEPA 2005).	Provides overview of elements in developing and implementing watershed protection plans
Handbook for Developing Watershed Plans to Restore and Protect our Waters. EPA-841B-08-002. (USEPA 2008d).	Describes processes and tools used to quantify existing pollutant loads, develop estimates of load reductions needed, identify appropriate management measures, and track progress

2.3.3 New Development and Redevelopment Strategies to Minimize Impacts of Development

The objective in new development is preventing additional runoff, pollutant loading, and the corresponding degradation in the watershed. Control measures focus first on the larger scale concepts such as smart growth (for example for overall facility siting), conservation design (for facility campus), and the use of LID practices distributed throughout a site. Many municipal entities have adopted such practices, and the concepts are also appropriate for use in planning and designing federal facilities.

Development Planning Techniques such as Smart Growth

New development creates extensive areas of impervious cover and increased runoff volumes. The developments are necessarily supported by additional roads and other associated infrastructure, compounding the effects. Facilities planners, and communities, should consider the cumulative effect of large-scale development, including the loss of natural areas and degraded streams and rivers.

Decisions about where and how to develop affect water quality perhaps more than any other factor. Preserving and restoring natural landscape features (such as forests, floodplains, and wetlands) is an integral part of green infrastructure. Efficient land use such as redeveloping already degraded sites can also serve to protect ecologically sensitive areas from development. Underused shopping centers or excess parking lot area can be targeted for development cost-effectively when considering that the supporting infrastructure is likely already in place. An example is the Naval Facilities Engineering Command Building 33 (NAVFAC Building 33), where the project's reuse of a brownfield site and reuse of an existing building were its most prominent green features (High Performance Federal Buildings Database, http://femp.buildinggreen.com/overview.cfm?projectid=495).

Development planning techniques such as smart growth should be used to accomplish the multiple goals of sound development with minimum detrimental effects on water quality. Sound principles of both smart growth and water quality protection can be achieved by using these approaches for new development, redevelopment, and retrofit. To achieve the common goals of smart growth and water quality protection, new development should be within or adjacent to existing development when possible.

The increases in local government costs of sprawl development patterns include increased costs for water distribution, sewer collection networks and maintenance, and increased school bus transportation cost. Locating facilities away from core services, and drawing accompanying housing development with it, could contribute to those types of costs. Note that it is difficult to state which growth pattern is ultimately the most challenging financially to a community as population pressures increase (Stephenson et al. 2001).

Examples of guidance for planning development are provided in Table 3-6. While such documents are usually prepared with a focus on municipal planning, the concepts are also applicable in many cases to federal facilities. Those documents also contain information on the water quality benefits provided by the pollution-avoidance strategies.

The Smart Growth Network has established the 10 primary principles of Smart Growth, which are listed in Figure 3-11. Many of these principles indirectly mitigate the impacts of growth on water resources, but the three listed in bold font, in particular, can be used to reduce or avoid the stormwater related impacts of both new development and redevelopment.

While several of the principles of smart growth apply, ones that can be most readily used to reduce the hydrological impacts of development and redevelopment activities are as follows:

- **Conserve Undeveloped Land** to preserve critical environmental areas. This maintains natural riparian buffers, floodplains, natural drainage ways, predevelopment hydrology, and watershed functions. Protecting natural areas such as forests, grasslands, and wetlands, and other open spaces that serve to filter, infiltrate, and evapotranspirate rainfall and snowmelt help maintain the stability of the watershed.

Table 3-6. Existing guidance on municipal smart growth approaches that are also applicable to federal facilities planning

Document	Highlights
Using Smart Growth Techniques as Stormwater Best Management Practices, www.epa.gov/dced/stormwater.htm	Detail policies and techniques that are integral non-structural stormwater practices
Smart Growth for Clean Water: Helping Communities Address the Water Quality Impacts of Sprawl, National Association of Local Governmental Environmental Professionals, Trust for Public Land, ERG www.nalgep.org/publications/PublicationsDetail.cfm?LinkAdvID=42157	Identifies approaches that can improve water quality, profiles successful local partnerships, and identifies barriers and solutions to implement smart growth for clean water programs.
Protecting Water Resources with Higher-Density Development, www.epa.gov/dced/water_density.htm (USEPA 2010c)	Provides research and example scenarios of how higher densities might better protect water quality—especially at the lot and watershed levels.
Water Quality Scorecard: Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scales www.epa.gov/dced/water_scorecard.htm	Provides policy guidance and case studies for protecting open space, promoting infill, designing better streets and parking lots, and adopting site-level green infrastructure practices.
Developing A Sustainable Community: A Guide to Help Connecticut Communities Craft Plans and Regulations that Protect Water Quality http://nemo.uconn.edu/publications/LIDPub.pdf	A guide to help users focus on where LID these practices can be integrated into a development policies.

- **Direct Development to Existing Communities and Infrastructure** to reduce the development of greenfields. This makes use of existing transportation networks, and reduces sprawl and the addition of new impervious surfaces. Redevelopment of existing communities and Brownfields can result in positive water quality impacts and limits the changes in land cover in undeveloped areas that result in stormwater volume increases (for more detail, see the redevelopment section of this chapter).

- **Use Compact Site Design** to reduce the extent of land disturbance, minimize infrastructure requirements to service the community, and reduce the overall impervious footprint (also see Conservation Design below).

- ***Create Range of Housing Opportunities and Choices:*** Providing quality housing for people of all income levels is an integral component in any smart growth strategy.
- ***Create Walkable Neighborhoods:*** Walkable communities are desirable places to live, work, learn, worship, and play and, therefore, are a key component of smart growth.
- ***Encourage Community and Stakeholder Collaboration:*** Growth can create great places to live, work and play—if it responds to a community's own sense of how and where it wants to grow.
- ***Foster Distinctive, Attractive Communities with a Strong Sense of Place:*** Smart growth encourages communities to craft a vision and set standards for development and construction that respond to community values of architectural beauty and distinctiveness, as well as expanded choices in housing and transportation.
- ***Make Development Decisions Predictable, Fair and Cost Effective:*** For a community to be successful in implementing smart growth, the private sector must embrace it.
- ***Mix Land Uses:*** Smart growth supports the integration of mixed land uses into communities as a critical component of achieving better places to live.
- ***Preserve Open Space, Farmland, Natural Beauty and Critical Environmental Areas:*** Open space preservation supports smart growth goals by bolstering local economies, preserving critical environmental areas, improving our communities quality of life, and guiding new growth into existing communities.
- ***Provide a Variety of Transportation Choices:*** Providing people with more choices in housing, shopping, communities, and transportation is a key aim of smart growth.
- ***Strengthen and Direct Development Toward Existing Communities:*** Smart growth directs development toward existing communities already served by infrastructure, seeking to use the resources that existing neighborhoods offer, and conserve open space and irreplaceable natural resources on the urban fringe.
- ***Take Advantage of Compact Building Design:*** Smart growth provides a means for communities to incorporate more compact building design as an alternative to conventional, land-consumptive development.

Source: The Smart Growth Network: www.smartgrowth.org/about/principles/default.asp?res=1024#top

Figure 3-11. The 10 primary principles of smart growth.

2.4 Use Conservation Design and LID Techniques

While planning techniques such as smart growth focus on where to locate development and redevelopment, conservation design techniques promote the best practices to mitigate the impacts of properly sited development. The design goal is to minimize the overall hydrologic modifications by protection of natural areas and ecosystem functions. Whereas watershed planning and smart growth address the *landscape or regional* scale, conservation design and LID practices address the community and site scales. Conservation design methods include the following (City of Portland 2004):

- Fitting development to the terrain to minimize land disturbance
- Confining construction activities to the least area necessary and away from critical areas
- Preserving areas with natural vegetation (especially forested areas) as much as possible
- On sites with a mix of soil types, locating impervious areas over less permeable soil (e.g., till), and trying to restrict development over more porous soils (e.g., outwash)
- Clustering buildings together
- Minimizing impervious areas
- Maintaining and using the natural drainage patterns

Existing guidance on conservation design is provided in Table 3-7.

Table 3-7. Existing guidance on conservation design approaches for municipal planning that also apply to federal facilities

Document	Highlights
Conservation Design for Stormwater Management: A Design Approach To Reduce Stormwater Impacts from Land Development and Achieve Multiple Objectives, Delaware Department of Natural Resources and Environmental Control and The Environmental Management Center of the Brandywine Conservancy, 1997 www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/Delaware_CD_Manual.pdf	Approaches, design procedures, and case studies.
Randall Arendt, Growing Greener: Putting Conservation into Local Plans and Ordinances, National Lands Trust-American Planning Association-American Society of Landscape Architects, 1999.	Evaluates the regulatory and zoning issues for implementing conservation design strategies
Site Planning for Urban Stream Protection, Tom Schueler/ Metropolitan Washington Council of Governments, 1995, www.mwcog.org/store/item.asp?PUBLICATION_ID=56	Reduce pollutants and protect aquatic resources through improved construction site planning.
Center for Watershed Protection www.cwp.org/Resource_Library/Better_Site_Design/index.htm	Library of References

Implementing these methods often requires an evaluation of institutional issues that influence growth and development. Using policies requiring compacting development, conserving open space, and protecting environmental assets is often impeded by facility planning guidance, or for municipalities, zoning requirements (Arendt 1999). When considering using conservation design policies to protect water resources, the issues should be examined both to determine if existing policies are promoting excess impervious area, and to identify impediments that could preclude adoption or implementation of more environmentally sound designs.

GI/LID Practices and the Treatment Train Approach

Many types of LID practices exist, with many variations of each practice. Projects are most successful when practitioners integrate them into a site design and use them in a treatment train approach. In such an approach, the overflow from one practice flows into a second or third practice, such as a green roof followed by a cistern, with the overflow to a planter box with its own overflow and underdrain. Site conditions, applicable performance requirements, and cost typically influence the selection of appropriate LID practices. Table 3-8 lists some of the major types of practices, and a fact sheet or link for each is provided in Appendix 1.

Table 3-8. Typical LID practices

LID BMPs for site plans	
Alternative Turnarounds[a]	Conservation Easements[a]
Development Districts[a]	Eliminating Curbs and Gutters[a]
Green Design Strategies[a]	Infrastructure Planning[a]
Narrower Residential Streets[a]	Open Space Design[a]
Protection of Natural Features[a]	Riparian/Forested Buffer[a]
Street Design and Patterns[a]	Urban Forestry[a,b]
Site-scale LID practices	
Bioretention (Rain Gardens)[a,b]	Rainwater Harvesting[b]
Green Roofs (Eco roofs)[a,b]	Blue Roofs with Water Harvesting[b]
Green Parking[a]	Grassed Swales[a]
Infiltration Trench[a]	Infiltration Basin[a]
Permeable Interlocking Concrete Pavement[a]	Pervious Concrete Pavement[a]
Porous Asphalt Pavement [a]	Vegetated Filter Strip[a]
Soil restoration[b]	Constructed wetlands[b]
Compost Blankets[a]	Infiltration Practices[b]

Notes

a. Fact sheet provided at http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5

b. Fact sheet provided in Appendix 1 of this chapter

The performance of LID practices in reducing the annual volume of runoff varies significantly according to the specific design of the practice and the regional climate. Depending on the site design and area rainfall patterns, runoff can be maintained at predevelopment conditions by careful site planning and design. Several design guides have been developed that detail the procedures for site analysis and LID practice sizing. Some of the best design guides for LID are provided in Table 3-9. Additional resources are listed in Appendix 2 and in the fact sheets in Appendix 1.

Table 3-9. Example nationally applicable LID design methods and manuals

Prince George's County, Maryland, *Low-Impact Development Design Strategies: An Integrated Design Approach,* EPA 841-B-00-003, 2000. Prince George's County, Maryland, *Low-Impact Development Hydrologic Analysis,* EPA 841-B-00-002, 2000. www.epa.gov/nps/lid/
USEPA, *Stormwater Best Management Practices Design Guide,* Office of Research and Development, EPA/600/R-04/121, Volumes 1-3 (121, 121A, 121B), September 2004. http://www.epa.gov/nrmrl/pubs/600r04121/600r04121.htm
Center for Watershed Protection *Urban Subwatershed Restoration Manual Series* (http://www.cwp.org/Store/usrm.htm) Center for Watershed Protection *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program* (http://www.cwp.org/Resource_Library/Center_Docs/SW/pcguidance/Manual/PostConstructionManual.pdf)
U.S. Naval Facilities Engineering Command, *Low Impact Development, Draft, Unified Design Criteria,* UFC 3-210-10, October 2004. http://www.wbdg.org/ccb/DOD/UFC/ufc_3_210_10.pdf
U.S. Army Corps of Engineers. *Low Impact Development for Sustainable Installations: Stormwater Design and Planning Guidance for Development within Army Training Areas.* Public Works Technical Bulletin 200-1-62. October 2008.
Geosyntec Consultants and Wright Water Engineers. *Urban Stormwater BMP Performance Monitoring.* 2009. http://www.bmpdatabase.org/MonitoringEval.htm
The Low-Impact Development Center, http://www.lowimpactdevelopment.org/; several LID manuals

Specific to the Chesapeake Bay area, a literature review and assessment of the reported performance of many LID practices was recently conducted for the region to estimate the capability of the practices for volume control and pollutant reduction. The Mid-Atlantic Water Program housed at the University of Maryland reviewed and compiled effectiveness estimates for BMPs implemented and reported by the Chesapeake Bay watershed jurisdictions (*Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus, and Sediment in the Chesapeake Bay* (Simpson and Weammert 2009) www.chesapeakebay.net/marylandBMP.aspx). The report estimates that the infiltration practices such as bioretention, as designed and with safety factor considerations, could reduce runoff from the first 1–1.5 inches of runoff up to 80 percent, for the purposes of conservatively estimating wide-scale effectiveness in the region. That depth is approximately the 85th to 95th percentile storm event in the region. The report was not meant to evaluate how currently designed practices would perform consistently in the 95th percentile storm event. Practices to achieve retention of the 95th percentile storm event would need to be designed for that specific target performance. Additional information on the findings are provided in Appendix 1 (1.1.1 *Performance Estimate Summaries for Infiltration Practices*) and in the Bioretention fact sheet in Appendix 1.

By using design procedures outlined in the LID manuals such as those in Table 3-9 and in Appendix 2 of this chapter, practices can achieve runoff reduction to restore or maintain predevelopment hydrology.

The effectiveness of conservation design using LID to reducing runoff is demonstrated in subdivision-wide results recently reported. Sources for information on existing LID subdivisions are provided in Table 3-10.

Table 3-10. Sources of information on existing LID subdivisions

Name, location, and reference	Performance summary
Meadow on the Hybelos, 8.27-acres Puget Sound area in Pierce County, Washington. www.sldtonline.com/content/view/344/75	2007 to 2008: LID subdivision designs performed better than design objectives, and exceeded the local requirement that post-development discharge volume not exceed predevelopment discharge volume. The researchers also reported that underdrains significantly impair hydrologic performance (WERF 2009).
Cross Plains, WI; Burnsville, MN; Somerset, MD: Jordon Cove, CT (ASCE/WERF/EPA International Stormwater BMP Database, *Urban Stormwater BMP Performance Monitoring*—Geosyntec Consultants and Wright Water Engineers 2009). www.bmpdatabase.org	Annual runoff reductions from 40% to 90% over the monitoring period were observed, with significantly reduced performance when rain events occurred under already saturated conditions.

2.5 Evaluate Planning Manuals and Guides

LID approaches and practices, smart growth and conservation development strategies can all be promoted by incorporating them into facility planning manuals and guides, similar to municipal codes and ordinances in some cases. Some aspects of existing planning manuals and guides can hinder LID development strategies because of the lack of understanding of the practices that in some cases differ from the traditional stormwater management approaches. For example, existing planning documents might require a curb and gutter that can serve to concentrate flows leading to increased volume of runoff to streams—one potential solution is to either drop the requirements for curb and gutter or state that curb cuts are encouraged to facilitate the use of roadside swale infiltration. Facility planning guides can also prevent naturalized landscaping, stormwater use in toilet flushing, and rain gardens that can have periodic short-term ponding. Resources that federal facility planners, municipal officials, and designers can use to evaluate codes and ordinances for revision to accommodate these approaches are provided in Table 3-11.

Table 3-11. Resources for evaluating codes and ordinances for municipalities that are applicable for use in reviewing federal facility planning manuals, guides, and specifications

Water Quality Scorecard: Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scales, USEPA 2010e, www.epa.gov/dced/water_scorecard.htm	Provides policy guidance and case studies for protecting open space, promoting infill development over Greenfield development, designing better streets and parking lots, and adopting site-level green infrastructure practices.
Out of the Gutter, National Resources Defense Council, July 2002 http://www.nrdc.org/water/pollution/gutter/gutter.pdf	NRDC recommends LID, for Washington, DC, including specific observation and recommendations for revisions to existing codes and ordinances.
A Catalyst for Community Land Use Change, National NEMO Network 2008 Progress Report: http://nemonet.uconn.edu/about_network/publications/2008_report.htm	Examples of local regulations for water quality protection.
Puget Sound Partnership Low Impact Development Local Regulation Assistance www.psp.wa.gov/downloads/LID/PSPSurveyLIDRegulAsistance_23April2010.pdf	Assistance to help local governments integrate LID into their development standards and regulations.
Better Site Design: A Handbook for Changing Development Rules in Your Community, Center for Watershed Protection, 1998 www.cwp.org/Store/bsd.htm	Examples and case studies for changing development regulations to promote better site design, also referred to as environmentally sensitive design or LID.
Plan Review checklist and flow chart, Office of Watersheds, Philadelphia Water Department: http://www.phillyriverinfo.org/WICLibrary/DevelopmentProcess_Final.pdf	Example of how to prioritize stormwater planning early in the overall plan review process for development projects.
Audit of Pavement Standards for the Saluda-Reedy Watershed, Mitigating the Impacts of Impervious Surfaces in Greenville and Pickens Counties, South Carolina, Saluda-Reedy Watershed Consortium c/o Upstate Forever, 2006. www.upstateforever.org	Identifies opportunities for flexibility in street width, parking ratios, sidewalk and driveway, and other aspects of paving.

The following list contains the most common elements of planning design requirements that can cause unnecessary construction of impervious surface areas that have applicability to federal facilities (CWP 1998 *Water Quality Scorecard*; USEPA 2009). Facility planners, similar to communities, should carefully review existing policy mechanisms to determine opportunities to revise to reduce water resource effects that can result from creating impervious surfaces:

- *Density patterns.* Dispersing low-density development across the watershed can negatively affect receiving waters by constructing significantly more impervious surfaces.

- *Street standards or road design guidelines* are used to dictate the width of the road, turning radius, street connectivity, and intersection design requirements. Facility planners should review street and road standards to determine if road designs can be changed to reduce impervious surface cover and still meet transportation and safety requirements.
- *Parking requirements* are generally set to the minimum, not the maximum, number of parking spaces required for retail and office parking.
- *Setbacks* are used to define the required distance between a building and the right-of-way or lot line. Many setback requirements specify the use of long driveways. Establishing maximum setback lines for buildings can reduce the creation of unnecessary impervious surface areas by bringing buildings closer to the street.
- *Height limitations* are used to limit the number of floors in a building. Limiting height can spread development out if square footage is unmet by vertical density.
- *Open space or natural resource plans* are used to identify land parcels that are or will be set aside for recreation, habitat corridors, or preservation. Such plans help communities prioritize their conservation, parks, and recreation goals and protect important areas from development.
- *Comprehensive plans* might be required by state law, and many cities, towns, and counties prepare comprehensive plans to support zoning codes. Federal facilities might have an opportunity to contribute to achieving the region's goals in the plan. Most comprehensive plans include elements that are intended to address land use, open space protection or creation, natural resource protection, transportation, economic development, and housing. These elements are important facets of a comprehensive watershed protection approach. Increasingly, local governments are identifying areas of existing green infrastructure and outlining opportunities to add new green infrastructure throughout the community to protect water resources.

2.6 Evaluate Transportation-Related Standards

Minimize/reduce impervious areas by using techniques such as reduced street widths and parking areas. Many urban and suburban streets are sized to meet code requirements for emergency service vehicles, on-street parking, and free flow of traffic. Such code requirements often result in streets being oversized for their typical everyday functions. The Uniform Fire Code requires that streets have a minimum 20 feet of unobstructed width; a street with parking on both sides would require a width of at least 34 feet. In practice, many suburban and urban streets can be much wider than that as local design practices have increased street widths to 40 and 50 feet. Those designs result in increased runoff and associated pollutant loadings. In sum, the two issues are often (1) planning documents often require excessively wide streets and do not specify a maximum width; and (2) the minimum requirement for widths is often exceeded.

Just decreasing the amount of impervious surface alone might not provide substantial stormwater benefits if the adjacent soils are highly compacted. Combining the reduced street width with the installation of swales or amended soil filter strips, or by using tree pits (even extending under paved sidewalks) to collect stormwater will provide enhanced performance.

Many communities have adopted narrower street width standards while also accommodating emergency vehicles by developing alternative street-parking configurations, designing adequate turnarounds, prohibiting parking near intersections, providing vehicle pullout space, and using smaller block lengths. Examples are provided in Table 3-12. A key to identifying and successfully codifying narrow street widths is coordination among departments, including fire, transportation, and public works.

Table 3-12. Examples of adopted narrow street widths

Jurisdiction	Street width (feet)	Parking condition
Phoenix, AZ	28	parking both sides
Orlando, FL	28 22	parking both sides, res. Lots < 55 feet wide parking both sides, res. Lots > 55 feet wide
Birmingham, MI	26 20	parking both sides parking one side
Howard County, MD	24	parking unregulated
Kirkland, WA	12 20 24 28	alley parking one side parking both sides—low-density only parking both sides
Madison, WI	27 28	parking both sides, <3DU/AC parking both sides, 3-10 DU/AC

ADT: Average Daily Traffic; DU/AC: dwelling units per acre

Source: Adapted from Cohen 2000; CWP 1998.
http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/narrow_streets.htm

The need to accommodate bike lanes and sidewalks adds to the pressure to increase width, making efficient design and incorporating permeable pavements where appropriate, even more important. Holistic design concepts such as *Complete Streets* (www.greenhighwayspartnership.org) describe broader function goals consistent with the focus of environment protection, such as lighting to prevent unnecessary glare and interference with off-road nighttime conditions.

Integrating green streets into overall development and redevelopment projects provides many opportunities for improving environmental and energy performance. For example, the small town of West Union, Iowa, evaluated combining its planned green street retrofit with a separately planned, energy-saving project to convert the central business district to sustainable geothermal energy. By adding pipes to convey excess geothermal energy underneath the planned permeable pavement in the green street, the town estimated it could save money in shoveling and plowing, reduce risk of ice patches, reduce salting costs, and, as a side-benefit, reduce salt runoff to the trout stream in the watershed. Such a project might not be achievable for capital cost reasons in many cases, but the long-term cost savings it provides demonstrates that it is well worth evaluation (http://www.iowalifechanging.com/community/downloads/West-Union-Iowa-Green-Streets-Pilot-Project-Summary.pdf).

Zoning requirements often require that parking be provided for the maximum business day, resulting in unused parking and impervious area for the majority of the year. Reassessing the actual needed parking area can minimize impervious area.

Green street and highway design is necessary to help mitigate the effects of stormwater runoff from those surfaces using roadside infiltration. A proven example of a green street is Seattle's pilot Street Edge Alternatives Project (SEA Streets), Figure 3-12, completed in 2001. It is an LID design that provides drainage that more closely mimics the natural landscape before development. Seattle Public Utilities accomplished this by reducing impervious surfaces to 11 percent less than a traditional street, by providing surface detention in swales, and adding more than 100 evergreen trees and 1,100 shrubs. Monitoring shows that the design has successfully reduced the volume of stormwater runoff by 99 percent http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/NaturalDrainageProjects/StreetEdgeAlternatives/index.htm.

Resources for additional information on street and highway design for LID are provided in Table 3-13.

Source: from http://courses.washington.edu/gehlstud/Precedent%20Studies/SEA_Street.pdf

Figure 3-12. Seattle SEA Streets

Table 3-13. Resources for information on street and highway design for LID

Document	Highlights
Green Highway Partnership (GHP), with weekly electronic newsletter, http://greenhighwayspartnership.org/	Tracks practices for green highways and green infrastructure, including innovative stormwater management, LID and transportation legislation.
Project 25-20(01): Evaluation of Best Management Practices for Highway Runoff Control, Low Impact Development Highway Manual, National Cooperative Highway Research Program, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_565.pdf	Provides scientific and economic information for selection and design of BMPs to control highway runoff, including BMPs to treat: nutrients, TPH, PAH, metals, pathogens, pesticides, temperature, TSS, trash.
Anacostia Waterfront Transportation Architecture Design Guidelines http://ddot.washingtondc.gov/ddot/cwp/view,a,1249,q,627063,ddotNav_GID,1744,ddotNav,|33960|.asp DDOT. 2005.	Guidelines for transportation design to support the economic and environmental health of the region, incorporating LID design practices.
Portland Green Street Program, Portland, Oregon, Bureau of Environmental Services (BES) www.portlandonline.com/BES/index.cfm?c=44407	Design information, project reports, technical guides, newsletter.
Tabor to the River, Portland BES www.portlandonline.com/bes/index.cfm?c=47591	Comprehensive, 500-street, watershed retrofit program detailed.
Natural Drainage Projects, Seattle, Washington, Seattle Public Utilities (SPU), www.seattle.gov/util/naturalsystems	Design information and details on LID street design and elements, porous pavement specification, project reports.

2.7 Minimize Directly Connected Impervious Areas in New Development, Redevelopment, and Retrofit

Not all impervious areas are created equal. Impervious areas that are directly connected to the storm sewer system convey excess stormwater volumes more rapidly and with greater impact than impervious areas that do not have a direct connection (i.e., are disconnected). The term *effective impervious area* (EIA) is used to describe this concept. EIA is the measure of how much impervious surface is directly connected to the conveyance system. One of the first steps to mitigating the effects of imperviousness is evaluating the opportunities to disconnect it so the rain can be infiltrated, evapotranspired, or harvested and used.

- **Downspout Disconnection.** Downspout disconnection is the process of separating roof downspouts from the sewer system and redirecting roof runoff onto pervious surfaces, most commonly a lawn, or to a stormwater management practices such as a bioretention cell or cistern.
- **Substituting Permeable Pavements for Conventional Pavements.** Using permeable pavements can reduce directly connected impervious area because pervious materials are substituted for impervious materials while maintaining the intended function. Permeable pavements can be used to infiltrate stormwater, making areas that were once a source of stormwater a means of reducing the volume of runoff. Similarly, green roof retrofits reduce the imperviousness of rooftops by using engineered soil media and vegetation to lower the runoff potential.
- **Maximizing Opportunities to Infiltrate, Evapotranspirate, and Harvest and Use.** Disconnect flows using infiltration and evapotranspiration by incorporating bioretention into street designs. Bioretention features can be tree boxes that collect stormwater runoff from the street (similar to conventional tree boxes), planter boxes, curb extensions, or bioswales. To adapt to street configurations, grades, soil conditions, and space availability, a range of shapes, sizes, and layouts can be used. Using existing rights-of-way and using techniques such as curb cuts to facilitate stormwater movement away from directly connected drainageways and into infiltration features are common practices.

Rainwater harvesting has recently become recognized as a stormwater management tool because of its ability to reduce stormwater runoff volumes from impervious surfaces. It also serves as a source substitute for potable water and can enhance water supplies and decrease the cost and impacts of supplying water to urban areas. Collected rainwater is ideal for nonpotable applications, such as landscape irrigation, toilet and urinal flushing, cooling system make-up, and vehicle washing. Such collection and use is a key component of an integrated water resources management approach. Performance of rainwater harvesting systems depends on the volume of water stored and the demand for the stored water.

Rainwater harvesting has been practiced by civilizations for centuries and is now actively used in many countries that experience chronic or seasonal water shortages. In this country, though, rainwater harvesting has been primarily used for flash flooding control, or otherwise managing drainage problems. Now, in states such as Georgia, Virginia, and Texas, government-supported organizations have prepared manuals and guidelines for residential and commercial water harvesting for drought preparedness. For a listing of manuals and other resources, see the fact sheet in Appendix 1. In the Northwest, residential and commercial rainwater harvesting is used for stormwater management. In western cities, rainwater harvesting is becoming more common—Los Angeles County and Tucson, Arizona, for example—but water rights issues could restrict its use in some states.

Design and installation manuals relevant to the Chesapeake Bay area, references to example city ordinances, and other information on rainwater harvesting are provided in the fact sheet in Appendix 1.

2.8 Implement Restoration

2.8.1 Native Landscapes and Urban Tree Canopy

Restoring native landscapes in drainage pattern and in plant selection can be an important component of restoring predevelopment hydrology. Information on native landscaping is available from many state and local governments and sources listed in the Section 5 Turf Management, and in the fact sheets in Appendix 1.

In the Chesapeake Bay watershed, trees constitute a large part of the native landscape and play a major role in the water cycle. That is not the case with other, arid regions, where supporting nonnative forests could strain water resources. In the Chesapeake Bay region, however, significant potential exists to reduce runoff volumes on an annual basis using increased urban tree canopy. Interception in the tree canopy provides some capture in small events, but trees can evapotranspirate significant amounts—up to 200 to 800 gallons per day for some mature tree species (ITRC 2009). Each deciduous tree in the Baltimore area in the 2009 weather pattern evapotranspired approximately the following amounts (during leaf-on period)(personal communication, David Nowak, U.S. Forest Service):

- 2.6 gallons/day for a small tree (1-m radius crown)
- 260 gallons/day for a large tree (10-m radius crown)

For dense urban environments—and where utility conflicts can be managed—new technologies include the following:

- Structures or structural soils that allow root growth under sidewalks and vehicle areas.

- Permeable pavements that enable stormwater to flow to roots while supporting loads.
- Flexible sidewalk material (example: Belleview, Washington, http://www.ci.bellevue.wa.us/rubber_sidewalk.htm.
- Large-diameter soaking hoses or vaults built into tree pits that collect and infiltrate a first portion of runoff for evapotranspiration.

Using those technologies, little or no additional land is consumed in managing stormwater, and some street tree maintenance issues can be better managed.

To estimate the effectiveness of adding urban tree canopy and green roofs at reducing the stormwater runoff volumes in a dense urban environment, Casey Trees and LimnoTech developed the Green Build-out Model to quantify the stormwater benefits of trees and green roofs for different coverage scenarios in Washington, DC (Casey Trees 2007). The model was applied to an *intensive greening* scenario and a *moderate greening* scenario. Nearly all the waters in Washington, DC, are seriously polluted by urban stormwater runoff and the sewage overflows it causes. The Green Build-out Model demonstrates that trees and green roofs—just a portion of the types of infrastructure practices available—can be used to achieve substantial reductions in stormwater runoff and sewage discharges to the rivers. Key findings show for an average year:

- The intensive greening scenario eliminates more than 1.2 billion gallons of stormwater.
- Reductions in stormwater runoff volume of up to 10 percent across the city, with up to 27 percent reductions in individual sewersheds under the most intensive greening scenario.
- The DC Water and Sewer Authority could realize between $1.4 and $5.1 million per year in annual operational savings in the area because of reduced pumping and treatment costs.
- General hydrological relationships, including unit area planning factors, and modeling methodologies that are transferable to other municipalities.

Using trees to help manage stormwater and protect water quality is increasingly accepted by some engineers and land managers as sustainability becomes more important in land design. A statement by the Chesapeake Bay Executive Council in 2006 emphasizes the point:

> Forests are the most beneficial land use for protecting water quality, due to their ability to capture, filter, and retain water, as well as air pollution from the air. Forests are also essential to the provision of clean drinking water to over 10 million residents of the watershed and provide valuable ecological services and economic benefits including carbon sequestration, flood control, wildlife habitat, and forest products.

A summary of resources for estimating stormwater management benefits of tree canopy are provided in Table 3-14. Additional information is provided in the Reforestation/Urban Forestry and Bioretention Fact Sheets in Appendix 1.

Table 3-14. Resources for estimating stormwater benefits of tree canopy and vegetation

Citygreen software by American Forests (2010a) www.americanforests.org/productsandpubs/citygreen *Trees Reduce Stormwater* website by American Forests (2010b) www.americanforests.org/graytogreen/stormwater	Analyzes the ecological and economic benefits of tree canopy and other green space.
i-Tree suite of software Tools from USDA Forest Service www.itreetools.org	Tools enable quantification on a per tree basis or on a watershed scale.
Phytotechnology Technical and Regulatory Guidance, The Interstate Technology & Regulatory Council, 2009	Provides guidance on using vegetation for soil remediation, and estimates of transpiration rates.
Casey Trees, Washington, D.C. Green Build-out Model. 2007. www.caseytrees.org/planning/greener-development/gbo/index.php	The Green Build-out Model demonstrated that trees and green roofs can be used to achieve substantial reductions in stormwater runoff and sewage discharges to the rivers.

2.8.2 Streams, Floodways, and Riparian Areas

Using stream and floodplain restoration, managers attempt to restore the ecological and hydrological functions and processes of a stream and its floodplain. The stream corridor is typically considered to consist of the stream channel, riparian zone, and flood plains (level areas near the channel, formed by the stream and flooded during moderate-to-high flow events). Stream corridors are influenced by the cumulative effects of upland and upstream activities and practices, including agricultural production, forestry, recreation, other land uses, or urban development. Specific restoration goals can include flood control, sediment control, improving drainage, stabilizing banks, and improving habitat. Correcting stream damage using stream restoration techniques is a costly undertaking with uncertain rewards; preventing the damage by using the techniques described in this guidance is a more reliable approach.

Restoring impaired waterways—in particular restoring the connection to the stream's floodplain to enable the streambank to overtop and spread excess flows out along the land to reduce velocity and allow for off-channel ponding and infiltration the length of the stream—is important to restoring predevelopment hydrology and reducing loading from larger and scouring flows. Degraded streams can themselves become a source of downstream pollution, such as when P-laden sediments are mobilized during high-flow events. In such cases, stream restoration can be a useful strategy to improve downstream water quality. It is important that the elevated flows causing sediment mobilization must also be addressed. Stream stabilization requires restoration of the stream's energy signature. The predevelopment hydrology of the watershed should be restored to regain the predevelopment character of the stream; however, in existing urban areas, that might be a longer-term goal. In urban areas, restoration by successive steps in the watershed and the stream might be desired.

A summary of existing information of the effects of stream hydromodification on the quality of the Chesapeake Bay is provided in Table 3-15. The studies demonstrate the importance of stream restoration and protection in achieving pollutant reduction in the Chesapeake Bay, particularly for sediment and the P that accompanies sediment loading.

Table 3-15. Studies quantifying the impact of sediment loading stream hydromodification on Chesapeake Bay water quality

Study	Findings
A Summary Report of Sediment Processes in Chesapeake Bay and Watershed, U.S. Geological Survey, Water-Resources Investigations Report 03-4123, 2003	Summarizes the impacts and sources of sediment and notes that sediment yield from urbanized areas can remain high after active construction is complete because of increased stream corridor erosion from altered hydrology
Schueler, T. The Practice of Watershed Protection, Technical Note #119 from *Watershed Protection Techniques 3(3):729–734*, Center for Watershed Protection, 2000.	Stream enlargement, and the resulting transport of excess sediment, is caused by urban development
U.S. Environmental Protection Agency. 2001. *Protecting and Restoring America's Watersheds: Status, Trends, and Initiatives in Watershed Management,* EPA 840-R-00-001. www.epa.gov/owow/protecting/restore725.pdf.	Straightened and channelized streams carry more sediments and other pollutants to their receiving waters. Up to 75% of the transported sediment from the Pocomoke watershed on the Eastern Shore of Maryland was found to be erosion from within the stream corridor
Gellis et al. 2007. *Synthesis of U.S. Geological Survey Science for the Chesapeake Bay Ecosystem and Implications for Environmental Management, Chapter 6: Sources and Transport of Sediment in the Watershed.* U.S. Geological Survey Circular 1316.	Sediment sources are throughout the Chesapeake Bay watershed, with more in developed and steep areas
Gellis et al. 2009. *Sources, transport, and storage of sediment in the Chesapeake Bay Watershed.* U.S. Geological Survey Scientific Investigations Report 2008–5186	In the Piedmont region, streambank erosion was a major source of sediment in developed Little Conestoga Creek; 30% of sediment from the Mattawoman Watershed on the Coastal Plain (flat land) is from streambanks
Devereux et al. *Suspended-sediment sources in an urban watershed,* Northeast Branch Anacostia River, Maryland. Hydrological Processes, Accepted 2009.	Streambank erosion was the primary source of sediment in the Northeast Branch Anacostia River

Stream restoration can help to restore the natural ecosystem function of N removal that occurs in streams. Studies that evaluate the N removal ability of restored streams are summarized in Table 3-16.

Table 3-16. Studies evaluating the N removal ability of restored streams in the Chesapeake Bay watershed

Study	Finding
Kaushal et al. *Effects of Stream Restoration on Denitrification in an Urbanizing Watershed.* Ecological Applications 18(3) 2008, pp. 789-804.	Streams with ecological functions intact remove N at a much higher rate than degraded urban streams, and stream restoration practices can restore this N removal function.
Klocker et al. *Nitrogen uptake and denitrification in restored and unrestored streams in urban Maryland,* USA. Aquatic Sciences, Accepted October 2009.	Degraded urban streams, deeply eroded and disconnected from their floodplain, have substantially lower rates of N removal that than streams hydraulically connected to their riparian banks via low slopes. Reconnecting the stream to the floodplain can increase N removal rate.

In addition to the water quality improvements that can be achieved through stream restoration, the flood management community has become increasingly aware of the benefits of restoration in preventing flood damages. The Association of State Floodplain Managers has prepared a white paper called *Natural and Beneficial Floodplain Functions: Floodplain Management—More than Flood Loss Reduction* (www.floods.org), which emphasizes the multiple benefits of protecting and restoring streams and their associated floodplains.

Techniques for stream and floodplain restoration are described in the *Hydromodification* chapter of this document. Example references for stream restoration, and for information on the effects of urban runoff on stream ecosystems, are provided in Table 3-17.

Table 3-17. References on urban stormwater effects on streams with emphasis on restoration and habitat

USDA Natural Resources Conservation Service, *Part 654 Stream Restoration Design National Engineering Handbook,* 210–VI–NEH, August 2007
Federal Interagency Stream Restoration Working Group (FISRWG) (1998*). Stream Corridor Restoration: Principles, Processes, and Practices,* ISBN-0-934213-60-7, Distributed by the National Technical Information Service at 1-800-533-6847.
Infiltration vs. Surface Water Discharge: Guidance for Stormwater Managers, Final Report. 03-SW-4, Water Environment Research Foundation (WERF 2006) Appendix B. Assessment of Existing Watershed Conditions: Effects on Habitat.

2.9 Reduce Impacts of Existing Urban Areas

2.9.1 Retrofits

Many urban areas were developed without any or with few stormwater controls designed to protect water quality and prevent stream channel degradation. This section contains recommendations for practices that can be used in such areas to try to reverse degradation that has already occurred by reducing the volume, rates, and duration of runoff. Specifically, the recommended control measures on existing urban land focus on retrofits to roof downspouts, roads, parking lots, and areas of compacted soils. While the suggestions are focused on stormwater management effectiveness, consideration should also be given to aesthetics when designing, and using a multidisciplined design team (engineer, landscape architect, maintenance staff) can result in more successful retrofits.

An effective retrofit strategy for urbanized areas combines planning techniques such as smart growth and green infrastructure/LID techniques. A comprehensive guide on retrofits for existing urban areas is the Center for Watershed Protection's (CWP's) *Urban Stormwater Retrofit Practices* (CWP 2007).

The CWP's *Urban Stormwater Retrofit Practices* manual focuses on stormwater retrofit practices that can capture and treat stormwater runoff before it is delivered to the stream. The manual describes both off-site storage and on-site retrofit techniques that can be used to remove stormwater pollutants, minimize channel erosion, and help restore stream hydrology. Guidance on choosing the best locations in a subwatershed for retrofitting is provided in a series of 13 profile sheets. The manual then presents a method to assess retrofit potential at the subwatershed level, including methods to conduct a retrofit inventory, assess candidate sites, screen for priority projects, and evaluate their expected cumulative benefit. The manual concludes by offering tips on retrofit design, permitting, construction, and maintenance considerations.

Table 3-18 presents common locations where additional storage and infiltration for stormwater can be provided in a subwatershed and common locations for on-site retrofits.

Table 3-18. Common locations for additional stormwater storage and infiltration and on-site retrofits

Common on-site retrofit locations in a subwatershed	
Where	**How**
Road Rights-of-Way	Direct runoff to a depression or excavated stormwater bioretention/infiltration treatment area within the right-of-way of a road, highway, transport or power line corridor. Prominent examples include highway cloverleaf, median and wide right-of-way areas.
Near Large Parking Lots	Provide stormwater infiltration treatment in open spaces near the downgradient outfall of large parking lots (5 acres plus).
Conveyance Systems	Investigate the upper portions of the existing stormwater conveyance systems (such as ditches) to look for opportunities to improve the performance. That can be done either by creating in-line storage cells (small dams with overflows) that allow infiltration or by splitting flows to off-line infiltration/treatment areas in the drainage corridor.
Hotspot Operations	Install filtering or bioretention treatment to remove pollutants from confirmed or severe stormwater hotspots discovered during field investigation.
Small Parking Lots	Insert stormwater treatment, preferably depressed bioretention or expanded tree boxes, in or on the margins of small parking lots (less than 5 acres). In many cases, the parking lot is delineated into a series of smaller, on-site treatment units.
Individual Streets	Look for opportunities with the street, its right-of-way, cul-de-sacs and traffic calming devices to infiltrate and treat stormwater runoff before it gets into the street storm drain network.
Individual Rooftops	Disconnect downspouts from storm drains, store and use the rainwater, and infiltrate excess stormwater runoff close to the source.
Little Retrofits	Convert or disconnect isolated areas of impervious cover to infiltration and bioretention, and treat excess runoff in an adjacent pervious area using low tech approaches such as a filter strip.
Hardscapes Landscapes	Reconfigure the drainage of high-visibility urban landscapes, plazas, and public spaces to capture and use, infiltrate and evapotranspirate, and treat excess stormwater runoff with landscaping and other urban design features.
Underground	Provide stormwater infiltration or treatment in an underground location when no surface land is available for surface treatment. Use this as a last resort at dense, ultra-urban sites.

Examples of LID road retrofits in the Chesapeake Bay watershed are included in Table 3-19.

Table 3-19. Examples of Maryland LID road retrofits

Site	Reference
Knollbrook Drive and Talbert Lane median and the Ray Road stormdrain outfall in the Takoma Branch subwatershed	*Final Technical Report, Pilot Projects for LID Urban Retrofit Program, In the Anacostia River Watershed, Phase IV,* USEPA: Prince Georges County, Maryland, 2007
U.S. Route 1 and Maryland Route 201 at I-95 (Bioretention)	www.princegeorgescountymd.gov/Government/AgencyIndex/DER/ESG/pdf/Final Technical Report Phase III.pd
Decatur Street Improvement, Edmonston, MD (holistic green street—multiple LID retrofits)	www.lowimpactdevelopment.org/greenstreets/projects.htm; http://edmonston.us.com/GreenStreetGroundbreaking.html
Route 202 Median (Bioretention)	www.co.pg.md.us/Government/AgencyIndex/GoingGreen/pdf/2009-annual-green-report.pdf
Route 201 Median (Bioretention)	www.co.pg.md.us/Government/AgencyIndex/GoingGreen/pdf/2009-annual-green-report.pdf
Peace Cross Green Highway Project—NW Prince George's County, adjacent to the Anacostia River. Network: • Baltimore Avenue • Bladensburg Road • Annapolis Road	www.princegeorgescountymd.gov/Government/AgencyIndex/DER/ESG/pdf/Final%20Technical%20Report_Phase%20III.pdf www.springerlink.com/content/l682122767u41k7x/fulltext.pdf
Route 202/I-495 interchange (Bioretention)	www.co.pg.md.us/Government/AgencyIndex/GoingGreen/pdf/2009-annual-green-report.pdf

2.9.2 Redevelopment

Implementing an effective redevelopment program is essential to restoring water quality, as discussed previously in this document. Section 4 of this chapter provides information on important issues that should be addressed in redevelopment policies and example practices that are appropriate for redevelopment. Figure 3-13 lists the stormwater retrofit and redevelopment programs that several cities have adopted or are piloting using GI/LID approaches. Implementation measures for redevelopment programs include establishing appropriate redevelopment performance standards, creating an inventory of appropriate mitigation practices for a range of project sizes, conducting site assessments as part of practice selection, reviewing planning policies (similar to municipal codes and ordinances), implementing demonstration projects, maximizing forest canopy, and mitigating compacted soils.

Some Municipal Highlights for Retrofit and Redevelopment Approaches and Practices:

Portland, Oregon, Bureau of Environmental Services: *A Sustainable Approach to Stormwater Management,* http://www.portlandonline.com/bes/index.cfm?c=34598

Seattle, Washington, Seattle Public Utilities *Natural Drainage Systems: Green Stormwater Infrastructure*, http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/index.htm

Kansas City, Missouri, *10,000 Raingardens* Program, www/rainkc.com/

Philadelphia, Pennsylvania, *Greenworks Philadelphia,* www.phila.gov/green

EPA's Green Infrastructure Web site: Case Studies of Green Municipalities, http://cfpub.epa.gov/npdes/greeninfrastructure/gicasestudies.cfm#Municipal

Figure 3-13. Municipal stormwater retrofit/redevelopment programs can provide insight to federal facilities for retrofit opportunities.

2.10 Costs of Green Infrastructure/LID Practices

This cost section provides sources for estimates of capital and O&M costs for individual practices and provides information that a policymaker or designer can use to help ensure that the cost savings and other benefits from GI/LID practices are considered during the decision process. This section presents examples from across the country that show how GI/LID practices compare financially to conventional stormwater management approaches.

The examples highlight municipal programs, but the concepts are applicable to cost evaluations on federal facilities.

The information is presented in the following format:

- Key factors in evaluating costs of GI/LID (section 2.10.1)
  - Planning and development processes that have a focus on LID and pollution prevention can help minimize the cost of implementing LID at the site level.
  - Flexibility of LID allows for practices to be integrated cost-effectively.
  - Opportunities for cost savings have been demonstrated and should be incorporated where feasible.
  - Environmental impacts downstream are a real and significant cost to society that should be included in determinations of development costs.

- Ancillary benefits such as vegetated urban spaces and habitat should be included when assessing the value of stormwater management alternatives.

- Types of cost analysis that can support decision making and examples (section 2.10.2)
  - Capital Cost assessment: Capitol Region Watershed District, Minnesota, and Lenexa, Kansas
  - Life-cycle cost analysis: Portland, Oregon, and Commonwealth of Virginia
  - Cost-effectiveness analysis: Mecklenburg, North Carolina, and New York City
  - Include ancillary benefits in life-cycle cost analysis
    - Local example: Philadelphia, Pennsylvania
    - Regional example: Sun Valley Watershed in Los Angeles
- Costs of individual practices (section 2.10.3)
  - Issues to be considered when evaluating reported costs
  - Sources of cost information

2.10.1 Key factors in evaluating costs of Green Infrastructure/LID

Planning and Development Processes

The most important practices to help ensure minimum cost for protecting water quality are the planning and development processes and their products, i.e., the master planning documents, specifications, municipal codes and ordinances, and other tools that promote development that minimize detrimental effects. Incorporating water quality protection into those processes does not cost more and provides multiple other benefits in addition to water quality. Implementing an LID approach, while site specific in application, can be more cost-effectively achieved when incorporated into an overall development policy. That can facilitate cost-effective designs and improved performance by

- Enabling developers and designers to understand that stormwater requirements are to be addressed in initial concept plans, and that the methods are acceptable to achieve a community's goal (i.e., Spotsylvania County, Virginia, Figure 3-14, and Middlesound, North Carolina, Figure 3-3), to reduce redesigns

The development community in Spotsylvania County has realized cost savings from LID, after initial skepticism. The county lists a few of the many successful LID projects:

- A historical church in a developed area needed to add-on but could not afford land for a basin, so instead used grass-pavers for the parking lot. An underground tank captures and infiltrates rainwater. Originally, a 42" diameter outlet was planned, now a 6" PVC pipe works, with minimal runoff. Used a rain garden before the drainage inlets. ***A 45% savings.***
- Patriot Park—This development had no outlet as a result of 1930's development design. Evapotranspiration rates were used to establish a potential water uptake. By using the required buffer and landscaping features the traditional basin was eliminated and there would be no downstream impact because up to a 100 yr storm event is retained on-site.
- Fence Company—The owner found that the bio-retention with underground storage cost approximately 30% less than a traditional basin with riser and land needed. Positives noted: 1) more land for material storage; 2) lower installation costs for installation; 3) easier to access and maintain.

"Spotsylvania has standardized agreements for BMP installation, inspection, and maintenance.

When it comes to the economics of LID practices for the most part you will not get an accurate figure until you show your applicants how to do it right. I have had farmers, homeowners, developers and many others say that after going through proper training courses they have found LID to be much easier than they have seen in the books and have been led to believe."

—Richard Street, Spotsylvania County, Virginia, Department of Code Compliance, January 2010

Figure 3-14. Developers realized LID cost savings in Spotsylvania County, Virginia.

- Ensuring that the type and scale of the practices implemented are appropriate to minimize maintenance costs and to provide amenity and habitat value for social acceptance (Seattle SEA Streets, Washington, Figure 3-12); Portland Tabor-to-the River, Oregon, Figure 3-2).
- Creating a market where such design and construction practices are routine to bring down costs associated with risk perception and limited materials. For example, when Chicago started the Green Alleys program in 2006, permeable concrete was about $145 per cubic yard; after one year, the cost dropped to $45 per cubic yard (*Managing Wet Weather with Green Infrastructure—Green Streets* (USEPA 2008)). Portland's green roof program notes that while literature values for green roofs cite an additional $5 to $25 per square foot, a focus on the bare minimum for a functioning eco-roof has reduced the additional cost to $3.50 to $8.00 per square foot (Portland BES 2008).

- Promoting practices that will help minimize overdesign and excess cost. For example, the use of permeable pavement should enable reduction of other stormwater drainage infrastructure (USEPA 2007).
- For some watersheds, reducing the costs of managing the increased flash flooding accompanying build-out of previously pervious area (Capitol Region Watershed District, Minnesota, Figure 3-19).

Flexibility for Integrating into Existing Infrastructure

Flexibility inherent in these practices allows the capture of small rain events to be integrated into the existing developed urban environment in many cases (NRDC 2006), such as blue roofs (New York City schools, Figure 3-15) that can serve as a first step in a treatment train to shave peak flows or store rainwater for use; landscaping features such as traffic islands, in-ground planters; or under-sidewalk systems (Minneapolis, Minnesota downtown MARQ2 street redevelopment project, Figure 3-16).

Here, blue roofs save money over conventional stormwater management practices for New York City school system for stormwater storage.

In 2003, the New York City School Construction Authority (SCA) adopted a new design standard requiring blue roofs, or roofs structurally capable of detaining water, on all new schools built citywide. In the past five years since adopting the requirement, SCA has built 14 new schools featuring the blue roof system. Essentially a blue roof is a drainage system that slows the rate water enters the public sewer system. Four aspects of the blue roof system determine its function: the structural integrity of the roof, the amount of water allowed to flow into the sewer, waterproofing of the roof, and the drain itself.

In the SCA's blue roof design, the roof drain detains up to three inches of water on the roof behind an adjustable weir valve. Any water in excess of three inches flows over the open top of the valve and into the sewers, but the detained water remains on the roof while being slowly filtered down the drain pipe.

For SCA, the decision to incorporate blue roofs in its design standard was driven by economics. DEP sets standards on the allowable flow of water to enter the public sewers from buildings, based on the local drainage plan and sewer capacity. To meet these drainage plan standards, any excess water must be stored on-site for delayed release into the sewer. SCA eliminated the need to build costly underground storage tanks at newly-built schools and additions by using a resource that was basically free: the roof. Since the engineering and design are already budgeted for in a new construction project, an integrated design to accommodate a blue roof adds very little or no additional upfront cost. And the maintenance and upkeep is no different than with a standard-drain roof.

SCA has been very satisfied with the cost-savings blue roofs afford them in building new schools and will continue to follow the standard in future projects.

—The City of New York *PlaNYC–Sustainable Stormwater Management Plan 2008*, p. 53.

Blue roof drain installed by the SCA on PS 12 (Photo credit: Council on the Environment New York)

Source: Forester Media, Inc. www.Forester.net. Excerpted with permission.

Figure 3-15. Blue roofs can serve as the first step in a treatment train to retain and use.

To reduce traffic congestion and refurbish its downtown, Minneapolis, Minnesota, recently completed the Marquette Avenue and 2nd Avenue (MARQ2) project, the first such effort aimed at reshaping transportation in the Twin Cities. Stormwater mitigation was a challenge. “We have long had capacity problems with stormwater management downtown,” says Lois Eberhart, water resources administrator for the city of Minneapolis. “We needed to find a new way of dealing with stormwater.” For 48 linear blocks, Minneapolis installed under-sidewalk structural cell frames to enable root growth for 185 trees. The project replaced previously impervious sidewalks with pervious pavement, allowing for greater infiltration and filtration of stormwater within the system.

Each cell group contains bioretention mix soil and can store 116 cubic feet (3.2 cubic meters) of stormwater. Over the entire project site, that’s nearly 21,600 cubic feet (611 cubic meters) of stormwater storage capability. The system is able to capture and treat the Minneapolis 90th percentile rain event (up to 1.03 inches, in a 24-hour period).

“We’ve modeled a 10% reduction in peak flows to our stormwater system as a result of this installation,” says Bill Fellows, project manager for the city of Minneapolis.

—Adapted from *Stormwater Magazine*, March-April 2010
www.stormh20.com/march-april-2010/reshaping-minneapolis-project.aspx

Figure 3-16. Under-sidewalk bioretention provides robust street trees as stormwater management benefit in the Minneapolis MARQ2 project.

Potential for Cost Savings

The potential for cost savings using LID where infiltration or drainage swales can be substituted for piping, inlets, and other stormwater infrastructure has been well-documented. Understanding the potential cost savings that can be achieved can help ensure that the most cost-effective designs are prepared. EPA's report, *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices* (EPA 841-F-07-006) (USEPA 2010d) compares the projected or known costs of LID practices with those of conventional development approaches. In terms of costs, LID techniques can reduce the amount of materials needed for paving roads and driveways and for installing curbs and gutters. Note that in some circumstances, LID techniques might result in higher costs because of more expensive plant material, site preparation, soil amendments, and increased project management costs. Other considerations include land required to implement a management practice and differences in maintenance requirements. Total capital cost savings ranged from 15 to 80 percent when LID methods were used (Table 3-20). The full report is at www.epa.gov/nps/lid.

Table 3-20. Cost comparisons between conventional and LID approaches

Project[a]	Conventional development cost	LID cost	Cost difference[b]	Percent difference[b]
2nd Avenue SEA Street	$868,803	$651,548	$217,255	25%
Auburn Hills	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall	$27,600	$5,600	$22,000	80%
Bellingham Bloedel Donovan Park	$52,800	$12,800	$40,000	76%
Gap Creek	$4,620,600	$3,942,100	$678,500	15%
Garden Valley	$324,400	$260,700	$63,700	20%
Kensington Estates	$765,700	$1,502,900	–$737,200	–96%
Laurel Springs	$1,654,021	$1,149,552	$504,469	30%
Mill Creek[c]	$12,510	$9,099	$3,411	27%
Prairie Glen	$1,004,848	$599,536	$405,312	40%
Somerset	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus	$3,162,160	$2,700,650	$461,510	15%

Source: *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices* (USEPA 2010d).

Notes:

a. Some of the case study results do not lend themselves to display in the format of this table (Central Park Commercial Redesigns, Crown Street, Poplar Street Apartments, Prairie Crossing, Portland Downspout Disconnection, and Toronto Green Roofs).

b. Negative values denote increased cost for the LID design over conventional development costs.

c. Mill Creek costs are reported on a per-lot basis.

Costs of Environmental Impacts

The environmental results of each alternative evaluated should also be considered when assessing true costs. Damages from water quality impairments are significant—even though they can be spatially distant from the widespread, incremental sources of excess runoff and pollutants. They are often not considered when determining the costs of stormwater management at the local level, but they are a true cost of stormwater management. For example, beach closures and shellfish bed contamination, and loss of fisheries represent significant social and economic costs to society. In addition literature available on the Chesapeake Bay, a national overview of some of these issues is provided in EPA's 2000 report *Liquid Assets* (http://www.epa.gov/water/liquidassets/execsumm.html).

Ancillary Benefits

The value of ancillary benefits that can be difficult to quantify should also be considered when establishing the costs or value of stormwater management practices that prevent excess volume of runoff. Examples of those types of benefits were provided in the introduction to this chapter. Examples of where such benefits have been realized are provided later in this section.

2.10.2 Types of Cost Analysis that Can Support Decision Making

Typical components of stormwater management costs include capital costs, O&M, and program administration. Stormwater management can also impose opportunity costs when selecting one alternative for implementation precludes another use, such as alternative use of a piece of land or funds.

Depending on the needs of the user, and assuming a similar level of risk and performance, alternatives are often selected on the basis of the following:

- Capital cost assessment
- Life-cycle cost analysis (net present value)
- Cost-effectiveness to achieve a specific goal, such as cost per pound of pollutant
- Including ancillary benefits in life-cycle cost analysis

The objective of these examples is to demonstrate how communities have found LID or green infrastructure to be an acceptable or superior alternative on a cost or cost-value basis. These examples will not be applicable to every federal facility or community, but are intended to illustrate the methods and factors being used by many communities to assess the cost of various stormwater management approaches.

Capital Cost Assessment.

Lenexa (Kansas) and the Capital Region Watershed District (Minnesota) are examples of communities that selected LID approaches to development and retrofit because of the lower capital costs compared to conventional stormwater management alternatives. Their case study examples are provided in Figures 3-17 and 3-18.

Lenexa, Kansas (population 47,000) was experiencing development pressures that led to adoption of LID-oriented development standards and a watershed-based systems approach to stormwater management. Program goals included reducing flooding, improving water quality, preserving the environment and open space, and providing recreational areas and trails.

A multi-stakeholder process to evaluate the cost impacts of the proposed standard included the Lenexa Economic Development Council and Homebuilders Association. The cost analysis evaluated different construction types, and compared the cost of construction under the LID standards to the costs of construction under the conventional standards. Each type of construction showed a capital cost decrease with LID standards:

Savings Associated with Different Development Types Using LID		
Development Type	EDUs	LID cost savings
Single Family	221	$118,420
Multi-Family	100	$89,043
Commercial/Retail	57	$168,898
Warehouse/Office	356	$317,483

Note: Savings includes additional developable land in addition to infrastructure. Equivalent Dwelling Unit: 2,750 sf.

The demonstrated savings not only helped gain developer support for the ordinance and the systems-based approach for stormwater management, but also helped ease the adoption of a development fee to help manage increasing stormwater infrastructure needs as the community grows. The ordinance was adopted in 2004, and 2009 polling data shows citizen satisfaction with the Public Works Department at 84%.

Sources: City of Lenexa Department of Public Works (personal communication), www.raintorecreation.org, Beezhold, M.T. et al (2006)

Figure 3-17. Lenexa, Kansas, demonstrates cost savings of implementing LID policies.

The Capitol Region Watershed District (CRWD) encompasses 41 square miles, including parts of St. Paul, Minnesota, and five smaller cities. The watershed is 42% impervious, almost completely developed, leading to impaired water quality and localized flooding.

In a 298 acre subwatershed of Como Lake, the initial solution to localized flooding was a second 60-inch storm sewer at a cost of $2.5 million, which would have continued the impairment of the lake from the additional urban runoff. In 2003, CRWD, in cooperation with local municipalities selected an alternative approach: retrofits consisting of an infiltration facility, eight under-street infiltration trenches, eight raingardens, and a regional pond.

The infiltration design performance was 100% for the infiltration facility, 100% for the rain gardens, and 93% for the infiltration trenches.

This approach has been a success. The following are the key benefits reported by CRWD on this project, called the Arlington Pascal Stormwater Improvement Project (APSIP):

- Capital cost savings of $0.5 million, on a project originally estimated at $2.5 million including water quality treatment not achieved with the original solution.
- Volume reduction (hence TP and TSS removal efficiencies) of 96% to 100%, in 2008 exceeding design projections
- Tracking of O&M activities and costs as well as actual and modeled performance enabled the estimation of the cost-effectiveness ($ per unit pollutant removed) of each practice (for amortized capital plus annual O&M as "cost"). In 2007, the APSIP BMPs infiltrated over 2 million cubic feet of runoff at a cost of $0.03/cf.

Source: Capitol Region Watershed District. 2010. CRWD Stormwater BMP Performance Assessment and Cost-Benefit Analysis. (www.capitolregionwd.org)

Figure 3-18. Midwest Water District achieves capital cost savings, solves localized flooding problems, and reduces lake impairment with LID retrofits.

Life-Cycle Cost Analysis

Portland, Oregon, conducted a life-cycle cost analysis of green roofs compared to conventional roofs. Green roofs are just one alternative being implemented in Portland to help manage the stormwater that causes flooding, erosion, destroys habitat, and contributes to CSOs. In the study, a hypothetical new five-story commercial building with a 40,000-square-foot roof in downtown Portland was evaluated. Key findings included the following:

- For the building owner (private interest), there was a net benefit over the 40-year life of the roof of $404,000 (2008 dollars)

- For the public, there was an immediate and long-term benefit. At year 5, the benefit is $101,660; at year 40, the benefit is $191,421. That does not include monetizing many environmental benefits that are recognized but difficult to quantify.

Benefits to the public were noted to include the following:

- Reduced public costs to manage stormwater
- Avoided public stormwater infrastructure needs and O&M costs
- Reduced carbon emissions
- Improved air quality
- Increased habitat areas

Benefits to private interests were noted to include the following:

- Reduced stormwater fees
- Reduced private infrastructure and O&M costs
- Reduced energy demand and costs
- Increased roof longevity

The report concludes that the lack of an immediate, short-term benefit to an owner accounts for the limited implementation of green roofs in Portland and beyond. The report recommends developing economic incentives to promote the use of green roofs (or *eco-roofs*) to encourage the construction in the city and to enable the city to benefit from the immediate, short-term benefits that they provide. For federal facilities that are long-term owners or have long-term leases, the opportunities for savings should be considered. The tabulated summary of benefits and costs is provided in Table 3-21 (Portland BES 2008).

Whether green infrastructure practices are more costly for a site than traditional stormwater management practices—or how much more they might cost—depends on many factors. They include the overall development's site drainage design, the land and groundwater characteristics, preference for site amenities, and, of primary importance, the design scenario selected for comparison. Administrative costs for implementing a program should also be considered.

Table 3-21. Private and public life-cycle cost and benefits evaluation of eco-roofs

Focus area	Cost		Benefits		Summary	
	One-time	Annual	One-time	Annual	5–year (in 2008 $s)	40-year (in 2008 $s)
Private Costs and Benefits						
Stormwater Management						
volume reduction				$1,330	$6,822	$45,866
peak flow reduction[a]				--	--	--
Energy						
cooling demand reduction				$680	$3,424	$19,983
heating demand reduction				$800	$4,028	$23,509
Amenity Value						
amenity value[a]				--	--	--
Building						
ecoroof construction cost	($230,000)				($230,000)	($230,000)
avoided stormwater facility cost			$69,000		$69,000	$69,000
increased ecoroof O&M cost		($600)			($3,077)	($20,677)
roof longevity (over a 40-year period)			$600,000		--	$474,951
HVAC equipment sizing			$21,000		$21,000	$21,000
Total Private Costs and Benefits	**($230,000)**	**($600)**	**$690,000**	**$2,810**	**$(128,803)**	**$403,632**
Public Costs and Benefits						
Stormwater Management						
reduced system improvements			$60,700		$60,700	$60,700
Climate						
carbon reduction				$29	$145	$845
carbon sequestration[a]				--	--	--
improved urban heat island[a]				--	--	--
improved air quality				$3,024	$15,515	$104,576
Habitat						
habitat creation			$25,300		$25,300	$25,300
Total Public Costs and Benefits	**$0**	**$0**	**$86,000**	**$3,053**	**$101,660**	**$191,421**
Total Costs and Benefits			**($27,143)**			**$595,053**

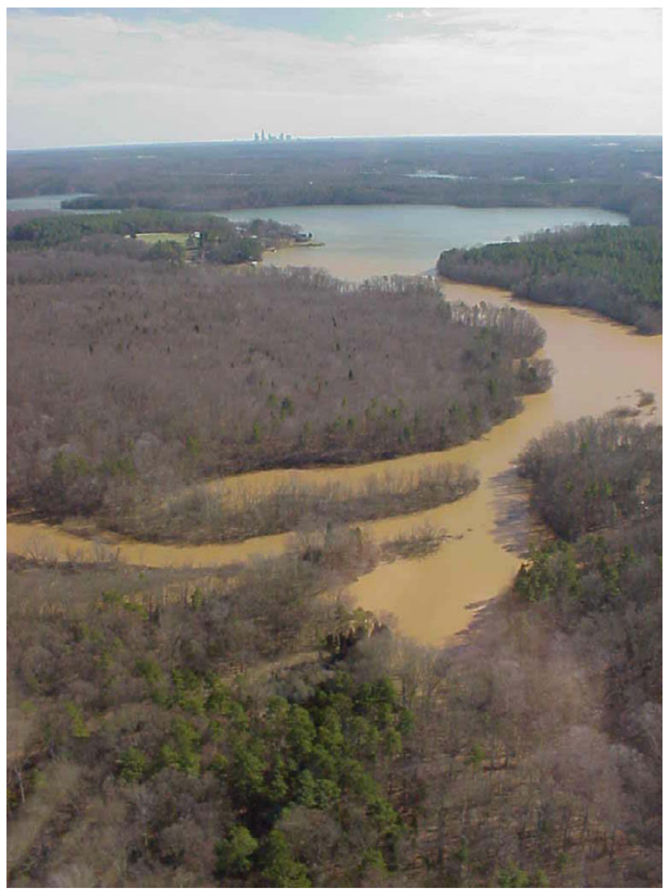
Source: City of Portland, Oregon, Cost Benefit Evaluation of Eco Roofs, 2008.

[a] The economic literature reports that an ecoroof can provide these economic benefits, however, data are unavailable at this time that would allow calculating a dollar amount for these benefits for an ecoroof in Portland.

In Virginia, a similar type of study was recently completed. To determine the financial impact of implementing new stormwater regulations, estimated additional costs were evaluated for a scenario of changing the stormwater management requirements to a proposed more stringent level (at the time, 0.28 lb/P/yr statewide; with a 10 percent reduction for redevelopment from previously developed site) with an emphasis on volume reduction. The report notes the environmental benefits of the proposed actions and the potential improvements in compliance options and effectiveness afforded by accounting for runoff reduction in loading reductions. The study concludes that while the incremental cost of the proposed regulations could not be estimated, new costs would be incurred on land development activities. Program administration costs were also noted as increasing, partially because of anticipated increases in tracking and in ensuring compliance with distributed infiltration systems, which, although smaller individually, would create a larger total number of practices requiring compliance tracking (Stephenson and Beamer 2008).

Cost-Effectiveness Analysis

Two cities that have conducted cost-effectiveness analyses on innovative and LID practices compared to traditional stormwater practices are Mecklenburg, North Carolina, and New York City. Each had significantly different situations to evaluate.



Source: McDowell Creek Watershed Masterplan, Charlotte-Meckenburg Stormwater Services 2006 <http://www.charmeck.org/Departments/StormWater/Projects/McDowell+Creek.htm>

Figure 3-19. Sediment entering Mountain Island Lake from McDowell Creek Cove.

Charlotte-Mecklenburg Stormwater Services is in a rapidly developing urban-suburban area. It has high sediment loads to the drinking water reservoir caused by the excess volume of urban runoff from development eroding local streams (Figure 3-19). Traditional stormwater management practices have not been adequate to prevent degradation. After a comprehensive watershed planning effort, the analyses demonstrated that LID policies should be implemented for development and that watershed retrofits were needed to protect the drinking water reservoir. The program focuses on in-stream restoration, upland BMP retrofits, and reforestation. Stream restoration was found to be the most cost-effective retrofit on *a dollar-per-pound-of-sediment-saved* basis, and extended detention was least the cost-effective means for sediment control retrofit in the watershed (Charlotte-Mecklenburg Water Services, McDowell Creek Retrofit and Restoration Master Plan at http://www.charmeck.org/Departments/StormWater/Projects/McDowell+Creek.htm).

New York City, like many older cities, has CSOs that routinely contaminate surface waters. Conventional solutions include constructing deep tunnels to store the excess stormwater-sewage mix. The high cost of the tunnels prompted the city to evaluate the cost-effectiveness of other solutions. The city determined that it was more cost-effective on a *dollar-per-gallon-saved* basis to implement new development standards, to require retrofits on building undergoing roof replacements to detain stormwater, and to implement LID retrofits such as green streets, than to rely on tunnel construction only. (PlaNYC, Sustainable Stormwater Management Plan, 2008 http://www.nyc.gov/html/planyc2030/html/stormwater/stormwater.shtml). The analysis does not consider the amenity benefits to the community, as was conducted in the Philadelphia analysis (Table 3-24).

One of the newer practices New York City found to be most promising is rooftop detention, or *blue roofs*. Rooftop detention can serve as a first step in a treatment train for peak shaving, or for storage for later use in irrigation, and so on. Cost observations were reported as follows:

> Rooftop detention, one of the measures most likely to be used to comply with the performance standard has low incremental costs. Compared to average costs of $18 per square foot for a typical four-ply roof, the costs of a blue roof are only $4 per square foot more. We assumed no additional maintenance costs above those incurred for a standard roof. When we consider lifecycle costs, the economics improve further, because the thicker membrane of blue roofs mean that they last longer than standard roofs; the warranty provided by manufacturers is 20 years, compared to 10 to 15 years for standard roofs. With approximate construction costs of $300 per square foot for new buildings, the cost of this strategy is little more than 1 percent of construction costs.

Source: The City of New York, PlaNYC, Sustainable Stormwater Management Plan 2008, p. 52.

The cost-effectiveness findings of these two communities are shown in Tables 3-22 and 3-23.

Table 3-22. Cost-effectiveness analysis of stormwater management practices is used to target the most cost-effective retrofit approach to reducing sediment loading to the drinking water reservoir in the McDowell Creek Watershed in Charlotte-Mecklenburg, North Carolina

Management practice	$ Per lb of sediment saved
Major system stream restoration/enhancement	$1.02
Minor system stream restoration/enhancement	$0.60
Sand filter	$24.43
Wet pond	$35.15
Wetland	$50.33
Rain garden	$19.55
Extended detention	$69.60
Vegetated swale	$3.89
Filter strip	$6.23
Pond retrofit	$1.88

Table 3-23. New York City's cost-effectiveness analysis demonstrates the cost-effectiveness of storage per gallon of runoff for new development standards, standards for existing building (during roof replacement), and LID retrofits compared to traditional CSO mitigation using tunnels. LID practices were among those with lower cost than traditional storage techniques.

Source control strategy	Cumulative runoff capture* (million gallons)	Cumulative PV cost (2010–2030) (millions)	Cumulative cost per gallon
Performance Standards for New Development	1,174	$105	$0.09
Performance Standards for Existing Buildings (plus preceding strategy)	2,838	$416	$0.15
Low- and Medium-Density Residential Controls (plus preceding strategies)	3,954	$625	$0.16
Greenstreets(plus preceding strategies)	4,178	$676	$0.16
Sidewalk standards (plus preceding strategies)	8,400	$1,704	$0.20
Road reconstruction standards (plus preceding strategies)	9,868	$2,123	$0.22
50% Right of way retrofits (plus preceding strategies)	24,092	$19,360	$0.80
Grey infrastructure reference case	Total CSO reduction	Total cost	Cost per gallon
Potential future CSO detention facilities	2,266	$2,337	$1.03

Notes:
* Cumulative runoff capture with the source control scenarios refers to gallons of stormwater runoff that can be retained or detained in those source controls. The city has not yet established the exact relationship between these quantities and the corresponding reduction in CSOs.
PV = Present Value

Source: PlaNYC – Sustainable Stormwater Management Plan, 2008, http://www.nyc.gov/html/planyc2030/html/stormwater/stormwater.shtml)

Locally evaluated benefits: Philadelphia. A broad range of societal benefits—and estimates of the monetary value associated with these benefits—are described in Philadelphia Water Department's (PWD's) *A Triple Bottom Line Assessment of Traditional and Green Infrastructure, Options for Controlling CSO Events in Philadelphia's Watersheds Final Report*, 2009. The categories of benefit accrual resulting from using green infrastructure stormwater management approaches are the following:

- Recreational use and values
- Property values, as enhanced by the LID options
- Heat stress and related premature fatalities avoided
- Water quality and aquatic habitat enhancements and values
- Wetland enhancement and creation
- Poverty reduction benefits of local green infrastructure jobs
- Energy usage and related changes in carbon and other emissions
- Air quality pollutant removal from added vegetation

Table 3-24 shows the benefits (and external costs) Philadelphia estimated for a 40-year period of two of the options compared for CSO solutions:

- A 50 percent LID and 50 percent conventional (tunnel) option
- An option consisting solely of conventional (tunnel) approaches

The 50 percent LID, or green infrastructure option, is a scenario in which 50 percent of the impervious surface in the CSO area is managed through green infrastructure and the remainder through conventional storage tunnels. The 30' Tunnel option represents a scenario where large tunnels would be used to manage the CSO. Philadelphia selected the options for analysis purposes, and they do not represent implementation decisions by the city. The table demonstrates the value of the ancillary benefits of using green infrastructure for CSO mitigation compared to the lack of ancillary benefits of traditional CSO management. Environmental performance of the two options is not estimated to be completely equivalent, which should be taken into consideration in fully comparing options.

Implementing those types of controls would be incremental over a development horizon time frame. Additional information on Philadelphia's program is provided in Section 4.

The cost estimates for construction and maintenance are in the Long-Term Control Plan at http://www.phillywatersheds.org/ltcpu/.

Table 3-24. Summary of Philadelphia's analysis of green infrastructure to help mitigate CSOs: Present value benefits of two options studied (Cumulative estimated through 2049 in 2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$524.5	
Improved aesthetics property value (50%)	$574.7	
Reduction in heat stress mortality	$1,057.6	
Water quality aquatic habitat enhancement	$336.4	$189.0
Wetland services	$1.6	
Social costs avoided by green collar jobs	$124.9	
Air quality improvement from trees	$131.0	
Energy savings usage	$33.7	$(2.5)
Reduced (increased) damage form SO_2 and NOx emissions	$46.3	$(45.2)
Reduced (increased) damage from CO_2 emissions	$21.2	$(5.9)
Disruption costs from construction and maintenance	$(5.6)	$(13.4)
Total	**$2,846.4**	**$122.0**

Source: Summary of Triple Bottom Line Analysis, City of Philadelphia Long-Term Control Plan, http://www.phillywatersheds.org/ltcpu/Vol02_TBL.pdf

a. 28' tunnel option in Delaware River watershed

Regionally evaluated benefits: Sun Valley Watershed, Los Angeles County. The Sun Valley watershed area of Los Angeles County experienced frequent flash flooding and a conventional storm drain pipe solution was proposed. However, the community initiated a process that prompted Los Angeles County to review more environmentally sound alternatives, particularly in light of the areas (1) severe drought conditions; (2) decreasing groundwater supplies; (3) high cost of the current practice of importing most of the region's water from sources including out-of-state; and (4) impaired water resources from urban stormwater runoff. The underlying regional stormwater management issues of rainwater loss, high demand, and the resulting high-energy-use water supply infrastructure is described in *A Clear Blue Future: How Greening California Cities Can Address Water Resources and Climate Challenges in the 21st Century* (NRDC 2008).

To select the best-value alternative, categories of benefits were developed. Various methods were used to quantify the benefits including using avoided costs, willingness to pay values from the literature, and valuation pricing (e.g. increases in property values). Project benefits (and costs) were evaluated over a 50-year horizon. The benefits evaluated included the following:

- *Flood Control*—Avoided cost of facilities needed to provide comparable local and downstream flood protection

- *Water Quality Improvements*—Avoided costs associated with removal of bacteria and other listed pollutants from waters that contribute to the Los Angeles River
- *Water Conservation*—Cost savings associated with using stormwater for groundwater recharge and water supply augmentation compared to purchasing imported water
- *Energy*—Cost savings associated the reduced energy consumption from planting shade trees and the decreased amount of energy used to pump imported water into the Los Angeles Basin under each alternative
- *Air Quality Improvements*—Absorption of pollutants by the tree canopy and reduced emissions from power plants from decreased energy consumption
- *Ecosystem Restoration*—Increased habitat and open space
- *Recreation*—Value of increased parkland and recreation for the area
- *Property Values*—Impact of project components on nearby property values

The costs of each alternative were monetized, including capital facilities costs, land acquisition costs, and expected O&M costs. The results of the benefit-cost analysis are summarized in Table 3-25, which shows the benefit-cost ratio for each alternative. The ratios use the present value of total project costs and benefits over the 50-year evaluation period. As a result of the analysis, an LID and infiltration alternative was selected and successfully implemented instead of the piped solution. The Los Angeles County Department of Public Works is now widely using this type of project analysis (Los Angeles County Department of Public Works 2004: http://www.sunvalleywatershed.org/ceqa_docs/plan.asp).

Table 3-25. Benefit/Cost ratio analysis for Sun Valley stormwater management alternatives shows that the storm drain pipe alternative provided less long-term value than LID/green infrastructure alternatives in a 50-year net present value analysis

Alternative	Storm drain pipe alternative	Alternative 1 infiltration	Alternative 2 water conservation	Alternative 3 stormwater reuse	Alternative 4 urban storm protection
Present value of total benefits (millions $ 2002 USD)	$73.44	$270.47	$295.39	$274.93	$239.95
Present value of total costs (millions $ 2002)	$74.46	$230.40	$171.58	$297.90	$206.61
Benefit-cost ratio	0.99	1.17	1.72	0.92	1.16

Note: A Benefit-Cost ratio greater than one indicates more benefits than cost.

2.10.3 Costs of Individual Practices

Given the considerations described above, it is clear that comparing the costs of individual LID practices to each other, or just to other stormwater management practices, is not the best way to fully evaluate the costs of LID practices or to convey the information on the economies that can be realized by efficient development planning. In addition to not accounting for these benefits, just stating practice cost does not show how costs can be optimized by integrating LID features into the landscape, or by selecting rooftop-to-stream incremental features to filter, treat, retain, capture and use runoff. A green roof might appear a relatively high cost practice, but in a densely urbanized area, it could be the most economical solution for stormwater management, and given the potential benefits shown in the Portland BES, Oregon, study (Figure 3-2), could be a worthwhile investment in the long term depending on the ultimate use for the building.

Issues that should be considered when estimating capital costs include the following:

- Because LID practices are relatively new, few examples of comprehensive, full-scale project costs are readily available, and costs that are available often represent higher pilot-scale or demonstration project costs.
- Limited literature values for costs often do not provide complete information needed, such as design/construction/startup information, or level of water quality treatment to be provided.
- Costs are highly site specific and are influenced by contractors' familiarity with the practices, and therefore vary considerably.
- LID practices are constructed primarily by using conventional construction techniques that can be readily estimated using local contractor quotes and industry guides such as *Reed Construction Data* (R.S. Means), as is done for conventional construction.

Issues that should be considered when evaluating O&M costs include the following:

- O&M will account for much of the ownership cost, so managers should consider the expected reliability and ease of maintenance when selecting a practice, not just the capital cost.
- Utilities maintenance staff are trained in management of conventional drainage systems, and changes might be needed for institutional programs for O&M to result in more cost-effective O&M that has been reported for maintaining pilot facilities.
- O&M costs attributed to LID practices were found to primarily be for aesthetics (WERF 2005), although more information is needed to determine what role aesthetics play in O&M costs reported. Many of the activities that would have occurred in regular nonfunctional landscaping (weed control, litter removal) are reported as LID maintenance. That can make it difficult to determine how much of the reported cost is actually an additional cost incurred to ensure that the practice functions.

- O&M costs for maintaining bioretention might be similar to the current maintenance costs for nonfunctional landscaping, in fact, they could be lower because bioretention would receive more rainwater and require less watering with potable water.

A wide range of potential cost outcomes for both capital and O&M are reported, such as

- Cost savings using LID is widely reported from minimizing conventional piped infrastructure and ponds, and simply using land and landscaping functionally.
- Higher cost can occur in dense, urban environments where cistern systems or green roofs might be costly but necessary because of land limitations.
- Limited cost savings or additional costs could be incurred if the local codes require installing minimum-sized piped systems regardless of LID design. This could be for flood control or other site-specific issues.

Estimates of stormwater management practice costs have been prepared by several entities and reflect the variability that is inherent in site-specific design and construction.

The determination of the most cost-effective practice is site-specific, depending on the availability of land, the local costs of labor and materials, and level of treatment required. The costs of individual practices are provided in the practice Fact Sheets in Appendix 1. General cost ranges and cost estimating approaches for LID and other stormwater management practices have been documented in the literature and are repeated here. References are provided in Table 3-26.

Table 3-26. Sources of general cost ranges and cost estimating approaches for LID practices

USEPA. 2004a. Stormwater *Best Management Practices Design Guide*, Office of Research and Development, EPA/600/R-04/121, Volumes 1-3 (121, 121A, 121B).
USEPA. 2004b. *The Use of Best Management Practices (BMPs) in Urban Watersheds,* Office of Research and Development, EPA/600/R-04/184.
CWP. 2007. *Urban Subwatershed Restoration Manual Series* (http://www.cwp.org/Store/usrm.htm)
Water Environment Research Foundation. 2005b. *Performance and Whole-Life Costs of Sustainable Urban Drainage Systems,* 01-CTS-21T
Water Environment Research Foundation. 2009. *Decentralized Stormwater Controls for Urban Retrofit and Combined Sewer Overflow Reduction, Phase II*.
Wiess et al. 2005. *The Cost and Effectiveness of Stormwater Management Practices,* Minnesota Department of Transportation, MN/RC – 2005-23.

However, to supplement existing information sources, some recent examples are summarized in Table 3-27, and some specific recent cost information from those sources is provided here.

Table 3-27. Sources of recent cost information for LID practices—capital, O&M, life cycle

Source	Key items
USEPA. *Reducing Stormwater Costs through Low-Impact Development,* Publication Number EPA 841-F-07-006 USEPA 2010d.	Savings of 15% to 80% found for LID subdivisions compared to conventional subdivision drainage practices.
ECONorthwest. T*he Economics of Low-Impact Development: A Literature Review,* November 2007	Case studies of LID costs and economic benefits
Natural Resources Defense Council. *Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows*; NRDC 2006. www.nrdc.org/water/pollution/rooftops/contents.asp	Policy guide for decision makers for LID; nine case studies of successfully used green techniques.
Fact Sheets in Appendix 1	Cost considerations associated with each practice presented.
City of Portland, Oregon, Bureau of Environmental Services, Sustainable Stormwater Management Pages, www.portlandonline.com/bes/index.cfm?c=34598	Extensive examples of green roofs and green streets, as well as other sustainable stormwater practices.
Water Environment Research Foundation. *WERF Cost Tool*, 2009. Free spreadsheet tool developed as part of *Performance and Whole Life Cost of Best Management Practices and Sustainable Urban Drainage Systems* (2005). Water Environment Research Foundation. www.werf.org/AM/Template.cfm?Section=Stormwater3	Provides estimates based on literature values. Intended for modification as needed for user project data. Calculates life cycle cost. Contains literature review by practice.
City of Philadelphia. *Long Term Control Plan Update, Supplemental Documentation, Volume 3, Basis of Cost Opinions*, September 2009; www.phillywatersheds.org/ltcpu/Vol03_Cost.pdf	Full range of LID costs for new, redevelopment, and retrofit. O&M costs. Anticipated cost reduction as practices become more widely used. Retrofit focus.
North Carolina Coastal Federation. *Low Impact Development Pilot Study to Reduce Fecal Coliform into Core Sound, Final Report,* Sea Grant Project Number: 07-EP-03, November 2008	Detailed costs for rain gardens, cisterns, conservation landscaping and other LID practices. Six implemented and 9 planned.
North Carolina State University (NCSU). Bill Hunt et al. *Evaluating LID for a Engineering Development in the Lockwood Folly Watershed*, North Carolina. www.nhcgov.com/AgnAndDpt/PLNG/Documents/Brunswick LID.pdf	Demonstrates the cost savings achievable using LID in place of conventional stormwater treatment.
New York City, Plan NYC, Appendix C, 2008, www.nyc.gov/html/planyc2030/html/stormwater/stormwater.shtml	For controls that are high-priority for retrofit.
City of Portland, Bureau of Environmental Services. Cost Benefit Evaluation of Ecoroofs 2008. www.portlandonline.com/bes/index.cfm?c=50818&a=261053	Quantifies the benefits to owner and public of installing green roofs
PWD. A Triple Bottom Line Assessment of Traditional and Green Infrastructure. Options for Controlling CSO Events in Philadelphia's Watersheds Final Report, 2009. www.phillywatersheds.org/ltcpu/Vol02_TBL.pdf	LID-based, green infrastructure approaches provide a wide array of important environmental and social benefits to the community, and that these benefits are not generally provided by the more traditional alternatives.

Sources of cost data for urban stormwater retrofits, especially roadway retrofits, include the following:

- Portland, Oregon's, Bureau of Environmental Services. For example, Portland notes in its description of its Tabor-to-the-River watershed green streets retrofit that resolves the drainage problems it faces using only pipe solutions would have cost an estimated $144 million, while adding sustainable, green stormwater management systems reduced the estimated cost to $86 million and enhanced water quality and watershed health (www.portlandonline.com/bes/index.cfm?c=50500&a=230066).

- Seattle, Washington's, utilities department, Seattle Public Utilities (SPU), has developed and adopted a green street design and retrofit approach it calls Natural Drainage Systems (NDS), started with the completion of the successful SEA Street project in 2001. (www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/NaturalDrainageProjects/index.htm). As part of the program's adoption, SPU conducted a benefit/cost comparison in 2003 between traditional designs and the NDS design. A summary is provided in Figure 3-20.

Local governments in the Mid-Atlantic area with cost data include the following:

- Philadelphia, Pennsylvania

- Montgomery County, Maryland

- North Carolina Division of Soil and Water's *Community Conservation Assistance Program* (CCAP)

Philadelphia Water Department (PWD). PWD conducted a cost analysis of wet-weather management approaches as part of its effort to screen and compare green-to-gray technologies in its Long-Term Control Plan Update (LTCPU). The costs for several of those technologies are provided here; for additional information and assumptions, see the LTCPU. In general, these are planning-level estimates, expected to fall in the range of –30 percent to +50 percent for the Philadelphia area.

Seattle Public Utilities—Natural Drainage System Program

Problem Statement: Seattle's receiving waters and aquatic life have been significantly impaired by the negative effects of urban stormwater runoff. Increasing volumes of runoff also cause flooding of roadways and property. Traditional methods of stormwater management and street design have proven to be ineffective at countering the effects of current and future development on receiving waters.

Natural Drainage Systems (NDS) is an alternative stormwater management approach that delivers higher levels of environmental protection for receiving waters at a lower cost than traditional street and drainage improvements.

- NDS targets areas of the city draining to creek watersheds that do not have formal drainage or street improvements.
- NDS design is based on technology that emphasizes infiltration and decentralized treatment of stormwater to reduce the total volume of runoff reaching creek systems.
- The goal of NDS is to more closely match the hydrologic function of natural forests that existed before development, thereby creating stable creek systems and clean water.
- NDS designs cost less than traditional drainage and street designs.

Cost analysis of natural vs. traditional drainage systems meeting NDS stormwater goals

Street type	***Local street*** **SEA Street**	***Local street*** **Traditional**	***Collector street*** **Cascade**	***Collector street*** **Traditional**	**Broadview Green Grid 15 block area**
Community Benefits	• One sidewalk per block • New street paving • Traffic calming • High neighborhood aesthetic	• Two sidewalks per block • New street paving • No traffic calming • No neighborhood aesthetic	• No street improvement • Moderate neighborhood aesthetic	• No street improvement • No neighborhood aesthetic	• Both SEA Street and Cascade types • One sidewalk per block • New paving • High neighborhood aesthetic
Ecological Benefits	• High protection for aquatic biota • Mimics natural process • Bio-remediate pollutants	• High protection flooding • Some water quality	• High water quality protection • Some flood protection	• High protection from flooding • Some water quality	• High water quality & aquatic biota protection • Some flood protection • Excellent monitoring opportunity
% impervious area	35%	35%	35%	35%	35%
Cost per block (330 linear feet)	$325,000	$425,000	$285,000	$520,400	Average per block: $280,000

Source: www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/index.htm

Figure 3-20. Comparison by SPU shows lower construction costs for NDS than traditional street design.

These costs were used as the basis for estimating the cost-to-benefits comparison of PWD's report *A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds*. The report indicates that the benefits from green infrastructure stormwater management are significant; those findings on benefit valuations are applicable even to non-CSO communities. To compare the costs of traditional versus green infrastructure, PWD assessed the capital, O&M, and life cycle costs for several stormwater management practices. It is important to note that the estimated costs were for facilities that would theoretically meet Philadelphia's stormwater ordinance, shown in Figure 3-21, to manage the first inch of runoff from directly connected impervious area, by infiltration possible, unless a waiver is obtained.

The Water Quality requirement stipulates management of the first one inch of runoff from all Directly Connected Impervious Areas (DCIA) within the limits of earth disturbance. The Water Quality requirement is established to (1) recharge the groundwater table and increase stream base flows; (2) restore more natural site hydrology; (3) reduce pollution in runoff; and (4) reduce combined sewer overflows (CSO) from the city's combined sewer systems. The requirement is similar to water quality requirements in surrounding states and in other major cities.

- The requirement must be met by infiltrating the water quality volume unless infiltration is determined to be infeasible (because of contamination, high groundwater table, shallow bed rock, poor infiltration rates, etc.) or where it can be demonstrated that infiltration would cause property or environmental damage.
- A waiver from the infiltration requirement must be submitted and approved if infiltration is not feasible... (continues)

Source: Philadelphia's *Stormwater Manual*; http://www.phillyriverinfo.org/WICLibrary/chapter%201.pdf

Figure 3-21. Philadelphia *Stormwater Manual* v2.0—Section 1.1.1 Stormwater Ordinance and Regulations

Cost estimate ranges for capital construction from PWD's Long-Term Control Plan for planning purposes are provided in Table 3-28 for redevelopment and for retrofit.

In addition to capital cost, PWD estimates the cost decrease that can occur as LID practices become more of a standard practice. In the LTCPU, PWD addresses many of the considerations in evaluating costs, including O&M schedules and costs and replacement costs. PWD LTCPU estimates that costs will decrease for the following reasons (PWD 2009):

- Improved site designs will result as designers learn to incorporate the new stormwater requirements into designs from the beginning. Now, such features are added to a site plan as an afterthought, resulting in higher design costs. Leaving more functional open space in the site design for stormwater management is assumed to occur over time, and designers will learn how to work with the expected site conditions.

Table 3-28. Summary of direct construction cost estimates from PWD's *Long-Term Control Plan Supplemental Documentation, Volume 3*

Control	Type	Minimum cost ($ / impervious acre)	Median cost ($ / impervious acre)	Mean cost ($ / impervious acre)	Max cost ($ / impervious acre)
Bioretention	Retrofit	$65,000	$120,000	$160,000	$410,000
	Redevelopment	$44,000	$90,000	$110,000	$200,000
Subsurface Infiltration	Retrofit	$65,000	$120,000	$160,000	$410,000
	Redevelopment	$44,000	$90,000	$110,000	$200,000
Green Roof	Retrofit	$430,000	$500,000	$500,000	$570,000
	Redevelopment	$200,000	$250,000	$250,000	$290,000
Porous Pavement	Retrofit	$65,000	$160,000	$160,000	$410,000
	Redevelopment	$44,000	$110,000	$110,000	$200,000
Street Trees	Retrofit	$18,000	$18,000	$18,000	$18,000
	Redevelopment	$15,000	$15,000	$15,000	$15,000

Source: Philadelphia LTCP; *Engineering News-Record* Construction Cost Index 7966; R.S. Mean 115.2

*From Philadelphia LTCP: Other cities have been experiencing costs in the range of $7–$16 per square foot ($305,000–$700,000 per impervious acre), with a typical range of $10–14 per square foot ($435,000–$610,000 per impervious acre). A recent green roof at Temple-Ambler campus was approximately $11 per square foot ($480,000 per impervious acre). The least expensive green roofs in Chicago, which has the largest-scale program in the U.S., are on the order of $6–7 per square foot ($285,000 per impervious acre), and this could be a reasonable estimate of what can be achieved in the future with a large-scale program in Philadelphia.

- Lower material costs are expected over time as the practices become more standard. The materials that are at a premium now because they are specialty items will become common. For example, PWD estimates that in the future, permeable pavement costs will be comparable to traditional pavement costs.
- Reduced design costs are expected as more designers become familiar with LID practices. PWD estimates that designs for LID projects will be on par with more standard designs.
- Reduced perception of risk will result in a lower contingency being applied to cost estimates.

The ranges of cost reduction expected by PWD over time from improved site design and lower material costs is approximately 20 percent up to about 25 percent.

Montgomery County, Maryland, LID Green Street Programs. Green street projects have been implemented for the past several years in Portland, Oregon; Seattle, Washington; and other locations. Montgomery County, Maryland, has undertaken several green streets projects, and recently compared the costs of its projects, both estimated and completed, with reported costs from other jurisdictions, as well as could be interpreted from the literature information provided. Limited data are available to date, and many factors contribute to the differences in costs reported, so the data might not be widely applicable. Table 3-29 presents a recent summary of the Montgomery County evaluation, with information added from Portland on its estimates.

Table 3-29. Summary of green streets cost evaluation

	Estimated level of WQ control	Total DA	Cost per acre DA (in $1,000s)		Cost per sf BMP SA (in $/sf)		Cost per impervious acre DA (in $1,000s)	
		(acres)	design	construction	design	construction	design	construction
Bioretention retrofit projects								
Montgomery County	100%	1.1[a]	$17	$112	$17	$113	$20	$131
Portland (Areas reported as impervious only)	100%	0.17[b]	$41	$214	$26	$136	$41	$214
	100%	0.21[c]	$10	$79	$8	$29	$10	$79
Prince George's County	66%	13.4[d]	$14	$104	$19	$139	$32	$233
	86%	1.5[e]	$72	$92	$99	$126	$217	$276
Swales and filter strip retrofit projects								
Montgomery County	16% to 50%	1.1 to 3.7[f]	$33 to $75	$26 to $84	$35 to $86	$39 to $44	$96 to $128	$40 to $143
Caltrans Swales	56%	0.20 to 2.4[g,i]	NR	$31 to $121	NR	$12 to $58	NR	$35 to $128
Caltrans Filter Strips	100%	0.49 to 2.42[h,j]	NR	$23 to $120	NR	$12 to $43	NR	$35 to $128
Burnsville, MN (less urbanized)	NR	5.3[j]	$12	$24	NR	NR	NR	NR

Source: Montgomery County, Maryland, and Portland, Oregon

Notes:

NR = Not Reported; DA = Drainage Area; SA = Surface Area; sf = square foot; Estimated Level of Control =

a. Dennis Ave. Health Center

b. 12th & Montgomery Ave.; Portland, OR, Report - only planter & pavers; http://asla.org/awards/2006/06winners/341.html

c. Green-Siskiyou, OR - curb planters, no subdrain, assume total DA (total impervious DA in report); http://www.asla.org/awards/2007/07winners/506_nna.html

d. Route 201 Gateway - roadway median retrofit

e. U.S. Rt. 1 at I-95 Interchange

f. Various projects, combination of completed costs and costs estimated for projects yet to be built

g. Various 2004 projects; include factors that increased the cost for dense urban retrofit (traffic control, etc.)

h. Various 2004 projects; include factors that increased the cost for dense urban retrofit (traffic control, etc.)

i. BMP Retrofit Pilot Program, Final Report, Report ID CTSW - RT - 01 – 050, California Department of Transportation, January 2004

j. Roadside swales and rain gardens; suburban community retrofits

Coastal North Carolina, Community Conservation Assistance Program (CCAP). Striving to protect its shellfish resources, North Carolina has encouraged LID since 1986. As a result, North Carolina has implemented a cost-share program to help start the adoption of new LID technologies. It developed cost information that it uses in the CCAP to estimate cost-sharing amounts. Table 3-30 provides a summary costs for coastal North Carolina for 2009.

Table 3-30. LID costs used by the North Carolina Division of Water Quality's *Community Cost Share Program*

BMP	Components	Unit type	All areas unit cost
Abandoned well closure		Each	
Backyard rain garden		SqFt	
	Bioretention excavation	SqFt	$5.00
	Bioretention soil amendment -sand	SqFt	$0.50
	Bioretention mulch	SqFt	$0.75
	Bioretention plants (installed)	SqFt	$1.50
Backyard wetland		SqFt	
	Wetland excavation	SqFt	$5.50
	Wetland plants (installed)	SqFt	$2.30
	Wetland outlet structure	Each	$50.00
Cisterns		Each	
	Cistern 250-1,000 gallons installed	Gallon	$1.75
	Cistern 1,000-3,000 galons installed	Gallon	$1.00
	Cistern 3,000 gallons installed	Gallon	
	Accessories package	Each	$700.00
	Cistern foundation	SqFt	$1.40
	Concrete pad for cistern	SqFt	$3.60
	Shipping charge	Each	
Critical area planting		SqFt	
	Grading - minimum	Job	$25.00
	Grading - light, 1" - 3" avg	100 SqFt	$3.90
	Grading - medium, 3" - 6" avg	100 SqFt	$4.82
	Grading - heavy, 6" - 9" avg	100 SqFt	$5.74
	Grading - extra heavy, 9" - 12" avg	100 SqFt	$6.66
	Grading - maximum heavy, more than 12" avg	100 SqFt	$7.58
	Vegetation (grass) - minimum	Job	$15.00
	Vegetation (grass)	100 SqFt	$0.75
	Vegetation (trees/shrubs)	SqFt	
	Vegetation - mulch, netting	100 SqFt	
	Vegetation - mulch, small grain straw	100 SqFt	$1.28
	Matting - excelsior, installed	SqYd	$0.95
Diversion		Feet	
	Excavation	SqFt	$5.00
	Vegetation (grass)	100 SqFt	$0.75
	Filter cloth-geotextile fabric	SqYd	$2.25
	Filter cloth-pins, metal anchor	Each	$2.00
	Vegetation - mulch, netting	100 SqFt	
	Vegetation - mulch, small grain straw	100 SqFt	$1.26
	Matting - excelsior, installed	SqYd	$0.95

Example Cost Comparison of LID Parking Lot and Conventional Parking Lot. When evaluating the costs of LID, it is important to compare to the costs of alternative stormwater management. The economies of subdivision development with LID practices have been documented (USEPA 2007). As an example, Table 3-31 presents a detailed breakdown of a cost comparison for two parking areas estimated for a project in Massachusetts, indicating that the LID construction cost was not higher than conventional costs. For this project, design costs were reported as higher because it was a relatively new type of design, but lower maintenance costs were anticipated.

Table 3-31. Comparison of conventional design vs. bioretention in two parking areas in Amesbury, Massachusetts

		Bioretention Area 1					Bioretention Area 2				
		Island = 51,155 SF (4,867 SF landscape)					Adjacent to clubhouse = 77,90 SF (19,584 SF landscape)				
		Quantity		Unit cost	Total cost		Quantity		Unit cost	Total cost	
	Item	LID	Standard		LID	Standard	LID	Standard		LID	Standard
Landscape	Loam (4" depth) (CY)	NA	59.6	$40	NA	$2,384	179	239.4	$40	$7,160	$9,576
	Bioretention soil mix (24" depth) (CY)	360.5	NA	$40	$14,421	NA	363	NA	$40	$14,520	NA
	Seed (SY)	240	541	$4	$960	$2,164	1360.8	1941	$4	$5,443	$7,764
	Composted, double shredded hardwood mulch (3" depth) (CY)	25	0	$28	$700	$0	68	20	$28	$1,904	$560
	Trees (EA)	18	18	$518	$9,315	$9,315	45	45	$518	$23,288	$23,288
	Shrubs (EA)	61	30	$32	$1,922	$945	216	108	$32	$6,804	$3,402
	Perennials and grasses (EA)	1450	0	$2	$2,900	$0	2068	0	$2	$4,136	$0
				total	$30,217	$14,808			*total*	$63,255	$44,590
Site work	HDPE Drain pipe (12" dia) (LF)	NA	55.4	$12	NA	$648	NA	148	$12	NA	$1,732
	Catch Basins (EA)	NA	2	$3,075	NA	$6,150	NA	4	$3,075	NA	$12,300
	Water Quality Units (Stormceptor STC 900) (EA)	NA	1	$8,000	NA	$8,000	NA	1	$8,000	NA	$8,000
	Curb (Extruded Concrete) Straight (LF)	NA	506.8	$6	NA	$2,914	NA	655.5	$6	NA	$3,769
	Curb (Extruded Concrete) Radius (LF)	NA	45.7	$8	NA	$356	NA	78.5	$8	NA	$612
	Wheel Stops (EA)	43	NA	$66	$2,838	NA	49	NA	$66	$3,234	NA
	Drain Manholes (EA)	NA	NA	$3,325	NA	NA	NA	1	$3,325	NA	$3,325
	Earthwork (CY)	NA	183	$5	NA	$860	NA	493	$5	NA	$2,317
	Pipe Bedding (CY)	NA	15.3	$2	NA	$36	NA	41.1	$2	NA	$96
				total	$2,838	$18,964			*total*	$3,234	$32,151
					Bioretention Area 1					***Bioretention Area 2***	
				total	$33,055	$33,772			***total***	$66,489	$76,740

Source: Eisenburg, Bethany, Design, Engineering, Installation, and O&M Considerations for Incorporating Stormwater Low Impact Development (LID) in Urban, Suburban, Rural, and Brownfields Sites, American Society of Civil Engineers (ASCE), Low Impact Development Conference Proceedings, 2008

3 Implementation Measures for Reducing Pollutant Concentrations with Source Controls and Treatment

Reduce pollutant concentrations by implementing source control measures and by treatment practices as necessary to meet water quality goals

Stormwater quantity control, along with source and pollution prevention controls, has been determined to be the most reliable means of achieving pollutant reduction and mitigating the many adverse environmental effects of excess urban stormwater runoff (National Research Council 2008). Many issues arise in the decision-making process of selecting stormwater controls. This section addresses some of those considerations related to source-control practice selection and stormwater treatment technologies.

This chapter does not address flood-control considerations. However, note that volume control practices can contribute to flood protection by infiltrating, evapotranspiring, and reusing precipitation that would otherwise contribute to floods. Although volume control is the most important tool to reduce the loadings of urban runoff pollutants to the Chesapeake Bay, some significant sources of pollutants are likely to require source control or treatment. They can include areas with vehicles or other urban/commercial/industrial activity.

A primary consideration in selecting stormwater management practices is the regulatory policy for the site and practice. Local, state, and federal regulations and policies apply, and managers should research these before site design and practice selection. Additional general information on how to choose among the many available stormwater runoff control practices is provided in *Decentralized Stormwater Controls for Urban Retrofit and Combined Sewer Overflow Reduction* (Weinstein et al. 2005).

Source Control/Pollution Prevention

Implementation Measures:

U-10. Identify the pollutants of concern (POCs) to help target the selection of pollution prevention/source control that are most appropriate, for example, nutrients and sediment.

U-11. Implement pollution prevention/source control policies, i.e., nonstructural, programmatic efforts as basic, routine land management practices to target specific pollutants.

U-12. Require source control practices on:

- New and redevelopment site plans for commercial/industrial facilities
- Commercial/industrial facilities through development of a
  - Stormwater Pollution Prevention Plan (SWPPP) where required for regulated industrial facilities.
  - Similar stormwater pollution prevention plans that may be required by local authorities or should be prepared for facility management.
- Municipal facilities or other designated Municipal Separate Storm Sewer System (MS4s) permittees through development of Pollution Prevention/Good Housekeeping programs such as the Stormwater Phase II Minimum Control Measures.

U-13. Develop and implement ongoing outreach programs aimed at behavior change to prevent pollution and control it at its source. Methods for impact and effectiveness evaluation should be incorporated into these outreach and education programs.

U-14. Implement programs for disconnection of directly connected impervious area, such as residential downspout disconnection programs.

U-15. Conduct inspections of commercial/industrial facilities to provide compliance assistance or to ensure implementation of controls.

Runoff Treatment

Implementation Measures:

U-16. Identify the POCs to help target the type of treatment approaches that are most appropriate

U-17. Select treatment practices based on applicability to the POCs

- Use practices to reduce runoff volume as the preferred and most reliable approach to reducing pollutant loading to receiving waters
- Use treatment practices as needed if reduction of runoff is not feasible
- Base the selection of treatment practice on
  - treatment effectiveness for the POC to ensure discharge quality
  - long-term maintenance considerations to ensure continued adequate maintenance and recognition of life-cycle costs
  - site limitations to ensure appropriateness of practice to the site
  - aesthetics and safety to ensure public acceptance

3.1 Source Control/Pollution Prevention

3.1.1 Identify Pollutants of Concern

Regulatory and Policy Drivers. POCs can be regulated by federal, state, or local requirements and policies. For the Chesapeake Bay, critical POCs are evident in the Chesapeake Bay Executive Order, which specifies that N, P, and sediment are POCs that must be controlled to successfully protect and restore the Bay.

Other examples of the types of regulations or issues that can result in specific types of pollutants being identified for reduction include the following:

- Narrative and numeric water quality standards at the federal, state, or local level.
- Specific National Pollutant Discharge Elimination System (NPDES) permit limitations.
- The Toxics Release Inventory makes available to the public annually collected data on the storage, release, and transfer of certain toxic chemicals from industrial facilities. Required under Emergency Planning and Community Right-to-Know Act, its primary purpose is to inform communities and citizens of chemical hazards in their areas.
- TMDL requirements under the Clean Water Act section 303(d) for water quality limited segments (www.epa.gov/owow/tmdl).
- States and local governments can develop watershed pollutant reduction goals, such as the Watershed Implementation Plans being prepared under the Bay TMDL (www.epa.gov/chesapeakebaytmdl/EnsuringResults.html?tab2=1).
- Other pollutants identified in studies evaluating urban runoff characteristics, such as metals from brake pad dust, toxic organics, petroleum hydrocarbons, pesticides and herbicides.

Predominant Land Uses. Specific land uses also contribute to the loading of certain pollutants. Land use type is one predictive indicator for the type of pollutants and typical pollutant loading that would be discharged during storm events. POCs and typical loadings from various land use types can be assumed using modeled data in the literature, such as from the 1983 Nationwide Urban Runoff Program (NURP) (see Table 3-32), or more recent sources. Models that can be used to estimate loading from land use types are provided in Appendix 2 of this chapter.

Table 3-32. Median stormwater pollutant concentrations from NURP study by land use

Pollutant	Units	Residential		Mixed		Commercial		Open space/ non-urban	
		Median	CV	Median	CV	Median	CV	Median	CV
BOD	mg/L	10	0.41	7.8	0.5	9.3	0.31	--	--
COD	mg/L	73	0.55	65	0.58	57	0.39	40	0.78
TSS	mg/L	101	0.96	67	1.14	69	0.85	70	2.92
Total Pb	µg/L	144	0.75	114	1.35	104	0.68	30	1.52
Total Cu	µg/L	33	0.99	27	1.32	29	0.81	--	--
Total Zn	µg/L	135	0.84	154	0.78	226	1.07	195	0.66
TKN	µg/L	1,900	0.73	1,288	0.5	1,179	0.43	965	1
Nitrate + Nitrite	µg/L	736	0.83	558	0.67	572	0.48	543	0.91
Total P	µg/L	383	0.69	263	0.75	201	0.67	121	1.66
Soluble P	µg/L	143	0.46	56	0.75	80	0.71	26	2.11

Source: Nationwide Urban Runoff Program (USEPA 1983)
CV = Coefficient of variation = standard deviation/mean

More recent quantification of urban pollutants is summarized in the *National Stormwater Quality Database* (NSQD) (Pitt et al. 2004). Tables 3-33 and 3-34 include excerpts from the summary report to highlight pollutant concentrations from typical urban land uses. It is noted that the NURP data and the NSQD data were collected using different protocols, as the NSQD data was collected by MS4s under the NPDES program protocols, and NURP data was collected using U.S. Geological Survey (USGS) protocols.

Table 3-33. Median concentration of typical stormwater pollutants from urban land uses

Land use	TDS (mg/L)	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	NH_3 (mg/L)	$N0_2+NO_3$ (mg/L)	Total Kjeldahl nitrogen (mg/L)	TP (mg/L)
Residential	72	49	9	55	0.32	0.6	1.4	0.3
Mixed Residential	86	68	7.6	42	0.39	0.6	1.35	0.27
Commercial	74	42	11	60	0.5	0.6	1.6	0.22
Mixed Commercial	70	54	9.25	60	0.6	0.58	1.39	0.26
Industrial	92	78	9	60	0.5	0.73	1.4	0.26
Mixed Industrial	80	82	7.2	40.4	0.43	0.57	1	0.2
Institutional	52.5	17	8.5	50	0.31	0.6	1.35	0.18
Freeways	77.5	99	8	100	1.07	0.28	2	0.25
Mixed Freeways	174	81	7.4	48	--	0.6	1.6	0.26
Open Space	125	48.5	5.4	42.1	0.18	0.59	0.74	0.31
Mixed Open Space	109	83.5	6	34	0.51	0.7	1.12	0.27

Source: Pitt et al. 2004

Table 3-34. Median concentration of typical stormwater pollutants from urban land uses

Land use	Oil and grease (mg/L)	Fecal coliform (mpn/ 100 mL)	As, total (µg/L)	Cd, total (µg/L)	Cr, total (µg/L)	Cu, total (µg/L)	Pb, total (µg/L)	Ni, total (µg/L)	Zn, total (µg/L)
Residential	3.9	8,345	3	0.5	4.6	12	12	5.4	73
Mixed Residential	4.4	11,000	3	0.8	7	17	18	7.9	99.5
Commercial	4.7	4,300	2.4	0.89	6	17	18	7	150
Mixed Commercial	5	4,980	2	0.9	5	17	17	5	135
Industrial	5	2,500	4	2	14	22	25	16	210
Mixed Industrial	4.75	3,033	3	1.6	8	18	20	9	160
Institutional	--	--	--	--	--	--	5.75	--	305
Freeways	8	1,700	2.4	1	8.3	34.7	25	9	200
Mixed Freeways	4	730	3	0.5	6	8.5	10	--	90
Open Space	1.3	7,200	4	0.38	5.4	10	10	--	40
Mixed Open Space	6	2,600	3	2	6	10	10	8	88

Source: Pitt et al. 2004

Virginia-specific event mean concentrations were analyzed from the NSQD for the Virginia Stormwater program (Center for Watershed Protection and Chesapeake Stormwater Network 2008). The analysis showed significant differences in Virginia data compared to national averages, resulting in recommendation for use of Virginia-specific data for setting statewide or jurisdiction-wide evaluations. Table 3-35 presents the summary of that analysis.

Table 3-35. Result of evaluation of NSQD stormwater runoff quality data comparing national and Virginia-specific EMCs

Parameter	Median EMC (mg/L)
Total Nitrogen	
National	1.9
Virginia	1.86
Residential	2.67
Non-Residential	1.12
Virginia Coastal Plain	2.13
Residential	2.96
Non-Residential	1.08
Virginia Piedmont	1.70
Residential	1.87
Non-Residential	1.30
Total Phosphorus	
National	0.27
Virginia	0.26
Residential	0.28
Non-Residential	0.23
Virginia Coastal Plain	0.27
Virginia Piedmont	0.22
Total Suspended Solids	
National	62
Virginia	40

CWP & CSN. 2008. The Runoff Reduction Method, Virginia Department of Conservation and Recreation,
April 18, 2008, Appendix G

Other sources of information on the types and concentrations of pollutants associated with land use types are provided in Table 3-36.

Table 3-36. Sources of information on typical pollutants by land use type

Reference	Information provided
Infiltration vs. Surface Water Discharge: Guidance for Stormwater Managers, Final Report. 03-SW-4, Water Environment Research Foundation (WERF 2006)	Appendix A. Assessment of Existing Watershed Conditions: Source of Stormwater Pollutants
Maestre, A., R. Pitt. *The National Stormwater Quality Database, Version 1.1, A Compilation and Analysis of NPDES Stormwater Monitoring Information.* Center for Watershed Protection, and EPA. 2005	Selected information from monitoring conducted for the NPDES Phase 1 stormwater program, from applications and subsequent monitoring, from 1992 to 2002. Approximately 3,765 events from 360 sites in 65 communities are included.

Watershed reconnaissance can be used to identify developed sites that might be hotspots of pollutants. Certain types of land uses, particularly industrial and commercial properties, can be significant sources of POCs that warrant source control and treatment control practices. Managers should evaluate such land use types to identify possible pollutant sources and determine their relative risk to water quality. Those reconnaissance efforts can help a municipality determine the following:

- Which land use(s) and activities are most common in the watershed
- What land uses(s) are expected to change in watershed
- The pollutants that would likely dominate in stormwater runoff, and the form of the pollutant (as total or dissolved, for example, or as organic nitrogen or ammonia) (can be more difficult to obtain)
- Any hotspot areas for the contamination

The identified pollutants are of concern regardless of whether they are impairing receiving streams.

Managers should review monitoring data from the watershed for the historical period of record to ascertain water quality characteristics and POCs. They should review water quality data for POCs to determine information regarding the form of the pollutant, such as

- Particle-size distribution
- Pollutant partitioning or fractionation
- Pollutant speciation, which affects bioavailability, toxicity, and treatability
- Whether the pollutant is exhibited during the first flush (WERF 2005)

That information should be used to determine which treatment unit processes or operations would be most appropriate if source controls are adequate.

Protecting existing uses, in addition to restoring impaired uses, is a critically important goal for restoring any waterbody. Areas of the watershed that are of high-quality and should be protected from degradation should also be identified. Table 3-37 provides resources for conducting watershed assessments to identify pollutant sources and to identify areas for additional protections.

Table 3-37. Sources of information on conducting watershed assessments

Reference	Information provided
National Management Measures to Control Non-point Source Pollution from Urban Areas, EPA-841-B-05-004. (USEPA 2005a)	Watershed assessment practices include examples of programs, methods to characterize watershed conditions and to establish indicators
Healthy Watersheds Initiative, www.epa.gov/healthywatersheds (USEPA 2010b)	Information on Healthy Watersheds, including - Approaches and benefits of conserving and protecting healthy watersheds - A systems approach to watershed assessment - Current assessment approaches being used by regions, states, and communities - Conservation Approaches & Tools - Outreach Tools - Links to projects at the national, regional, state, and local scales

A review of results of industrial/commercial facility inspections can indicate whether these types of properties are likely to become hotspots for pollutants. Additionally, managers can review reports of illicit discharges, illegal connections, and illegal dumping to determine if there are patterns in discharges that might not be predicted by land use alone, which would indicate a need for additional outreach and education or enforcement activity. Information from past inspections and investigations can also help to identify areas with legacy pollutants (spills, dumping, and so on) that need to be addressed before certain types of infiltration practices could be used. Also, managers can evaluate local planning documents to identify potential future land uses that might become sources of pollutants.

A generalized approach for a site assessment is to

1. Identify potential sources

- By type—commercial, industrial, transportation
- By risk—of spills, leaks, illicit discharges

- By using existing commercial/industrial databases, land use maps, field investigations, permit applications

2. Prioritize using
   - Pollutants of Concern (POCs)
   - Spill or discharge potential
   - Sensitivity of watershed
   - Past operation experience
3. Generate a list of potential hotspot areas prioritized according to the magnitude and severity of risk
4. Inspect and follow up for implementing corrective measures

References for conducting site assessments are provided in Table 3-38.

Table 3-38. Resources for conducting site assessments and implementing P2 BMPs

Reference	Information provided
Urban Subwatershed and Site Reconnaissance Users Guide. Manual 11 (Wright et al. 2005) www.cwp.org/Resource_Library/Center_Docs/USRM/USRM11_Appendix_C.doc	Includes a Hotspot Site Investigation (HSI) procedure, which quantifies a facility's impact and identifies possible BMPs needed. An inspection form is used to characterize the site, quantify impacts, and identify BMPs.
Urban Subwatershed Restoration Manual No. 9: Municipal Pollution Prevention/Good Housekeeping Practices (Novotney et al. 2008) www.cwp.org/Resource_Library/Center_Docs/municipal/USRM9.pdf	Guidance on how to improve ten key areas: municipal hotspots, municipal construction, road maintenance, street sweeping, storm drain cleanouts, stormwater hotlines, landscaping and park maintenance, residential stewardship, stormwater maintenance, and employee training
Urban Subwatershed Restoration Manual No. 8: Pollution Source Control Practices (Schueler et al. 2005) www.cwp.org/Resource_Library/Center_Docs/USRM/ELC_USRM8v2sls.pdf	Includes methods to assess subwatershed pollution sources, more than 100 regulatory and incentive options, 21 specific stewardship practices for residential neighborhoods, and 15 pollution prevention techniques for control of stormwater hotspots
California Stormwater Best Management Practice Handbooks (CASQA 2004) www.cabmphandbooks.com/industrial.asp	Guidance on preparing stormwater pollution prevention plans, fact sheets for a variety of source and treatment control BMPs, and information on monitoring, reporting, and evaluation
EPA's Menu of BMPs www.epa.gov/npdes/menuofbmps	Pollution Prevention/Good Housekeeping for Municipal Operations BMP Fact Sheets

Aesthetic Issues. Finally, water quality issues that are important to the community should help to determine POCs. For example, if a pond in a public park is being filled with sediment because of upstream construction or algae growth is excessive, sediment and nutrients are POCs for that pond's subwatershed.

3.1.2 Implement Pollution-Prevention and Source-Reduction Policies

Managers should review facility policy and specifications, state and local regulations, standards, and policies, as well as the ongoing pollution-prevention programs, to determine how they can be improved. Identify regulations, incentives or a combination of both that would be most appropriate to address the POC through source reduction or treatment. Evaluate the pollution prevention/source control program to ensure that it is using the most recent approaches and is being effectively implemented.

The following are examples of types of regulations and programs to be considered for POCs:

Excess pollutants from excess runoff

- Disconnection of directly connected impervious area, such as incentives for use of permeable pavement or for downspout disconnection

Nutrients (for additional information, see the Turf Management Section)

- Fertilizer limitations on use
- Phosphate ban (e.g., laundry detergent phosphate bans in Virginia (1988), Maryland (1985), District of Columbia (1986), and Pennsylvania (1990))
- Free yard care consultations/soil testing (e.g., services offered by cooperative extension agencies)

Pesticides

- Inspections of commercial/industrial storage and application procedures (e.g., as part of NPDES industrial facility inspections)
- Integrated Pest Management (IPM) incentives
- Example resources: Urban Pesticide Pollution Prevention (UP3) Project, www.up3project.org

Trash, Oil & Grease, Pathogens

- Stormwater ordinance that addresses trash, commercial loading areas, and such

- Fats, oils, grease program (e.g., JEA FOG program in Jacksonville, Florida)
- Pet waste ordinance (e.g., Virginia Beach Ordinance #1237, www.vbgov.com/file_source/dept/planning/Document/LynnhavenFecalReport2006.pdf)

Sediment

- Erosion and sediment control ordinance (EPA model erosion and sediment control ordinance)
- Disturbed area restoration ordinance
- Tree preservation ordinance (see the Reforestation Fact Sheet)
- Buffer ordinance (EPA model aquatic buffers ordinance)
- Erosion and sedimentation control certification requirements
- Runoff volume control ordinance

Hydrocarbons, Oil/Grease

- The Spill Prevention Control and Countermeasures (SPCC) rule includes requirements for oil spill prevention and response, including requirements for specific facilities to prepare and implement SPCC plans
- Requirements for covers and berms for fueling and fuel storage areas
- Green business certification to reward businesses that have taken tangible steps toward environmental sustainability (e.g., Bay Area Green Business Program)
- Metals
- Restrictions on the amount of copper and other metals contained in brake pads sold in Washington State in the future (State Senate Bill 6657, signed March 19, 2010) (http://www.washington.edu/admin/pb/billtracker/)

Resources for information on pollution prevention and source reduction practices and programs are provided in Table 3-39.

Table 3-39. Resources for information on stormwater pollution prevention practices

CZARA/6217 http://coastalmanagement.noaa.gov/nonpoint/welcome.html
EPA's National Management Measures to Control Nonpoint Source Pollution from Urban Areas, 2005 www.epa.gov/owow/nps/urbanmm/index.html
EPA's Education Resources for Non-Point Source Runoff (USEPA 2010a) www.epa.gov/owow/nps/eduinfo.html
EPA Menu of BMPs www.epa.gov/npdes/stormwater/menuofbmps
California Stormwater Quality Association (CASQA) Industrial and Commercial, Handbook www.cabmphandbooks.com/industrial.asp
2005 Stormwater Management Manual for Western Washington: Volume IV -- Source Control BMPs www.ecy.wa.gov/biblio/0510032.html
Source Water Protection Practices Bulletin: Managing Stormwater Runoff to Prevent Contamination of Drinking Water, EPA 816-F-09-007 (USEPA 2009c) www.epa.gov/safewater
Source Water Protection Practices Bulletin: Managing Highway Deicing to Prevent Contamination of Drinking Water, EPA 816-F-09-008 (USEPA 2009d) www.epa.gov/safewater
Pollution Prevention Resource Exchange, a clearinghouse for pollution prevention information www.p2rx.org

3.1.3 Implement Source Control Practices

Source controls are the most cost-effective approach to reducing pollutant concentrations; however, to be effective, such controls must be adopted and properly maintained. Some source controls must be implemented as part of the design of the facility itself, such as ensuring that vehicle maintenance operations are conducted in an area where contaminated stormwater will not run off the site.

Table 3-40 shows some examples of source control implementation strategies targeted at specific pollutants. Those strategies are used in many municipal good housekeeping programs and might have applicability at federal facilities—most importantly those that are regulated as MS4s. The Stormwater Phase II Final Rule includes, in addition to local government jurisdictions, certain federal and state-operated small MS4s. Federal-operated small MS4s can include universities, prisons, hospitals, military bases (e.g., state Army National Guard barracks), and office buildings/complexes. The final rule requires the permittee to choose BMPs for each minimum control measure. (USEPA 2005b. *Stormwater Phase II Final Rule: Federal and State-Operated MS4s: Program Implementation* EPA 833-F-DD-D12 www.epa.gov/npdes/pubs/fact2-10.pdf)

Table 3-40. Pollution-prevention and source control practices used widely by municipal programs might have applicability to federal facilities

Strategy/BMP	Nutrients	Pesticides	Pathogens	Sediment	Metals, oil/grease
Require source controls on new and redevelopment site plans for commercial/industrial facilities					
• Require LID/infiltration practices where appropriate (not substitute for pollutant source control, and avoid hotspots)	•	•	•	•	•
• Mandatory storm drain marking for all inlets in maintenance yards, parking lots and along sidewalks	•	•	•	•	•
• Elimination of curb and gutter in favor of bioswales where feasible, particularly in residential or suburban areas	•	•	•	•	•
• Covered dumpster areas			•		•
• Covered outdoor loading/unloading areas that drain to sanitary sewer connections			•		•
• Covered fueling areas					•
• Native plant landscaping	•	•		•	
• Irrigation management	•	•		•	
• Develop leaf collection programs and composting/reuse programs	•	•		•	
• Disconnected roof gutters to minimize parking lot runoff			•	•	•
• Curb cuts to allow parking lot runoff to run into landscaping			•	•	•
Implement downspout disconnection program	•	•		•	
Provide pollution-prevention education					
• Native plant landscaping	•	•		•	
• Soil preparation, restoration, and amendments (composting)	•	•		•	
• Water conservation (e.g., irrigation management)	•	•		•	
• Integrated Pest Management	•	•			
• Household hazardous waste disposal and used oil recycling		•			•
• Car wash education				•	•
• Pet waste management	•		•		
Require source control activities					
• Cover materials/minimize exposure				•	•
• Fleet maintenance conducted inside or under cover					•
• Spill kits and response					•
• Spill training for all staff					•
• Parking lot maintenance			•	•	•

Table 3-40. Pollution-prevention and source control practices used widely by municipal programs might have applicability to federal facilities *(continued)*

Strategy/BMP	Nutrients	Pesticides	Pathogens	Sediment	Metals, oil/grease
Conduct inspections of commercial/industrial facilities to provide compliance assistance or require implementation of controls or both					
Implement source control measures					
• Cover materials/minimize exposure				•	•
• Fleet maintenance conducted inside or under cover					•
• Spill kits and response					•
• Spill training for all staff					•
• Street sweeping street sweeping at a monthly interval (or more frequently) along all curbed roads with speed limits of 35 MPH or less in urban/suburban areas; use regenerative air sweeper technology			•	•	•
• Parking lot maintenance			•	•	•
Establish dog walking areas with signage and locations to properly dispose of dog waste			•		
Inspection high-priority construction projects at high frequency				•	•

The types of pollutants controlled through this strategy will depend on the materials used/stored and the activities conducted at the facilities.

Federal facilities that often require industrial stormwater permit coverage that can contain SWPPP requirements include (www.fedcenter.gov) the following:

- General Services Administration (federal government construction)
- Naval Facilities Command (transportation vehicles)
- U.S. Army Corps of Engineers (DoD construction)
- Bureau of Reclamation (transportation vehicles)
- Other facilities that perform industrial activities, have vehicle fleets, and frequently undergo building construction

Some specific examples of leading municipal programs around the country that might provide information applicable to federal facilities include the following:

- New Jersey's Stormwater Program that includes a comprehensive storm drain marking requirements (http://www.state.nj.us/dep/watershedmgt/DOCS/StormDrainLabeling.pdf)

- San Mateo Countywide Water Pollution Prevention Program, which offers pollution prevention tips geared toward citizens, business owners, and municipalities (http://www.flowstobay.org)
- Seattle Public Utilities' Integrated Pest Management Program and ProIPM Fact Sheets (http://www.seattle.gov/UTIL/Services/Yard/For_Landscape_Professionals/Integrated_Pest_Management/index.asp)
- North Carolina Division of Pollution Prevention & Environmental Assistance's Web site, including the P2 infoHouse, a searchable database of pollution prevention resources (http://www.p2pays.org)

A recent source control program in the District of Columbia is the fee on the disposable bags from retail stores. Bags represent 47 percent of the trash in Anacostia River tributaries. The nickel-per-bag fee is an effort to reduce litter and generate funds to clean up the Anacostia River. The *Washington Post* reported that the fee was having a big effect within 3 weeks from the program's start, reports were that the fee had cut the use of plastic bags by half or more (*Washington Post*, Saturday, January 23, 2010). Reducing such nonessential waste at federal facilities should be considered, and federal facilities should consider supporting that type of initiative undertaken by the local governments.

3.1.4 Public Outreach

Many state and federal agencies require some form of outreach or public education and involvement as part of their water quality laws and regulations. That type of outreach is also applicable for federal facilities, particularly those with MS4 coverage. For example, Phase II of EPA's NPDES stormwater regulations, which requires MS4 operators to develop and implement stormwater management programs, state that localities are to provide opportunities for citizens to participate in developing the program and that they distribute educational materials on stormwater runoff. In all communities, whether regulated as MS4s or not, developing an effective outreach campaign will help gain the critical support and compliance that will lead to the ultimate success of a stormwater management program. Making the public aware of the issues, educating them on what needs to be done, and motivating them to take action will help managers meet both regulatory and water quality objectives.

Changing behavior through education and developing responsible attitudes among watershed citizens and communities is not a simple task. EPA has provided resources to help communities educate local citizens on how to protect local water quality through their own actions. EPA has published *Getting In Step: A Guide to Conducting Watershed Outreach Campaigns.* See http://www.epa.gov/watershed/outreach/documents/. *Getting In Step* approaches outreach using concepts from social marketing. Social marketing means looking at the target audience as consumers. Instead of selling products or services, social marketing sells ideas, attitudes, and behaviors. The goal of social marketing is not to make money, but to improve society and the environment. Social marketing campaign examples include the popular slogan “Only You Can Prevent Forest Fires.” Such campaigns persuade the public that a problem exists that only they can solve. For example, if the goal is to encourage people to test their soil before they apply lawn fertilizer, make it easier for them: sponsor a soil test day on which a local garden supply store hands out free soil test kits and demonstrates their use. This approach will go a lot further toward getting people to test their soil than merely sending out a flyer in the mail.

Getting In Step provides the overall framework for developing and implementing an outreach campaign in concert with an overall water quality improvement effort. It presents the outreach process as discrete steps, with each step building on the previous ones. The steps are as follows:

- Define the driving forces, goals, and objectives
- Identify and analyze the target audience
- Create the message
- Package the message
- Distribute the message
- Evaluate the outreach campaign

The *Getting in Step* guide includes worksheets to help develop an outreach plan, information on additional resources for outreach and education, publications, and other available outreach materials.

EPA also provides the Outreach Toolbox (http://www.epa.gov/nps/toolbox/) for organizations to use to educate the public on stormwater runoff. The toolbox contains a variety of resources to help develop an effective and targeted outreach campaign. Features of the nonpoint source Outreach Toolbox are

- *Featured Products*—Exemplary outreach examples culled from the catalog for increasing awareness and changing behaviors across each of the six targeted topics (general stormwater and storm drain awareness, lawn and garden care, pet care, septic system care, motor vehicle care, and household chemicals and waste) and organized by media type.
- *Searchable Catalog*—Contains more than 700 viewable or audible TV, radio, and print ads and other outreach products to increase awareness and/or change behaviors across six common topics (see Featured Products). Search by media type or topic. Permissions

for using the cataloged products are disclosed (and in most cases, granted) by the product owners, and contact information, campaign Web sites, and other pertinent details are provided.

- *Other Nonpoint Source Outreach Collections*—Links to collections of nonpoint source outreach and educational products compiled by states and other organizations.

3.1.5 Disconnecting Directly Connected Impervious Areas, Such as Downspout Disconnection

In many urban areas, roof downspouts are connected to the storm sewer system or, in some cities, to combined sewer systems. Disconnecting the downspouts allows the roof runoff to drain to the lawn or garden and infiltrate. Disconnection might not be applicable in all situations, depending on safety and property protection needs of each site. One example of a municipal downspout disconnection program is in Baltimore, Maryland (at http://baywatersheds.org/wp-content/uploads/2010/03/DownsputDisconnectionBrochure2010.pdf). The program, which targets sites in the Herring Run and Jones Falls watersheds, provides free surveys and disconnections for homeowners. The program also helps residents install rain barrels and rain gardens.

3.1.6 Inspections of Commercial/Industrial Facilities

A pollution-prevention program should include a component that tracks commercial/industrial activity and includes conducting routine and random inspections of commercial/industrial facilities. The program can be used to provide compliance assistance or to ensure implementation of controls, such as those required under a municipal ordinance. The activity is an integral component of the NPDES MS4 stormwater permit requirements, and technical guidance on approaches for inspection programs—for MS4 communities or for other entities—is provided in EPA's *MS4 Program Evaluation Guidance,* Chapter 4.6 Industrial/Commercial Facilities, January 2007, http://www.epa.gov/npdes/pubs/ms4guide_withappendixa.pdf. This guidance can provide useful information in implementing a program or survey of industrial/commercial operations at federal facilities.

In addition, the Chesapeake Stormwater Network has developed a *Stormwater Pollution Benchmarking Tool for existing industrial, federal and municipal facilities in the Chesapeake Bay Watershed* (http://csnetwork.squarespace.com/whatsnew/csn-releases-technical-bulletin-7.html). The tool guides facilities through a comprehensive assessment of its site to identify stormwater problems and retrofit opportunities, using 22 stormwater benchmarks. The tool also helps facilities develop an action plan to enhance stormwater pollution-prevention efforts at their individual facility.

Examples of stormwater inspection programs for commercial/industrial facilities that might be useful for federal facilities include the following:

- Contra Costa, California *Commercial & Industrial Business Inspection Plan,* 2005, http://www.ci.brentwood.ca.us/pdf/npdes/commerial_industrial_inspection_plan_05.pdf

- Sacramento County Stormwater Quality Program, http://www.sactostormwater.org/industrial/compliance.asp

Key technical components of an inspection program that might be applicable to federal facilities include the following (USEPA 2007):

- *Facility Inventory.* Characterize the facilities and prioritize them on the basis of their potential effect on stormwater quality, and the inspection program should be based on that prioritization approach.

- *Tracking.* A database facilitates program management. The database inventory should include facility type, past inspection or enforcement results, proximity to receiving waters, potential pollutant sources on-site, and other pertinent information to assist in inspection prioritization and management.

- *Standards, BMPs, and Outreach.* Many facilities have stormwater-specific stormwater management standards for industrial and commercial facilities to protect water quality and minimize stormwater pollution. Developing brochures, fact sheets, and posters to hand out to operators during inspections is useful for educating them about appropriate BMPs and inform them of what to expect from the inspection program.

- *Staff Training.* Routine training to ensure that inspectors are knowledgeable is essential to minimizing stormwater pollution from industrial/commercial facilities. It is important to cross-train any other staff used for stormwater inspections as well.

- *Inspections.* Most effective industrial/commercial inspection programs maintain a complete facility inventory and group them according to site-specific priorities. Inspection frequency is determined according to priority. An inspection standard operating procedure should be formalized and documented. It should include a checklist to be used during the inspection and possibly a report format. Inspectors should be aware of federal, state, and local stormwater regulations that might apply to industrial/ commercial facilities. Inspectors should be familiar with various types of BMPs commonly used at the types of facilities being inspected and should be able to educate facility operators about such BMPs. Inspections should be used to identify noncompliance issues and as an opportunity to educate facility operators about proper stormwater BMPs.

- *Program Support and Resources.* Inspection programs should be included in the operating budget.

3.2 Runoff Treatment

3.2.1 Identify Pollutants of Concern

Approaches for identifying POCs are discussed under section 3.1.1. For the Chesapeake Bay, POCs include N, P, and sediment. Source control and pollution prevention are the most effective means for reducing pollutant concentration, used with runoff minimization. Treatment should be used as needed, in addition to the measures of pollutant reduction and runoff minimization to mitigate the identified POCs.

3.2.2 Select Treatment Practices Appropriate to the POC

Treatment Practices and Design Guides. Treatment controls for stormwater, and estimates of their effectiveness, have been summarized in the literature. Example references are provided in Table 3-40. In general, the effectiveness for removing virtually all pollutants, with the exception of gross solids and heavy particulates, is highly variable because of the differences in practice design, nature of pollutants, changes in watershed conditions, and variability in storm characteristics (*Stormwater Best Management Practices (BMP) Performance Analysis,* December 2008, prepared for EPA by Tetra Tech).

Table 3-41 also includes references to sources of information on manufactured devices that might be useful as pretreatment before LID practices.

Table 3-41. References on general stormwater treatment BMP type, effectiveness, and design approaches

Reference	Information provided
Stormwater Treatment BMPs	
EPA's *Stormwater Best Management Practices Design Guide,* Volumes 1-3 (121, 121A, 121B), September 2004. U.S. Environmental Protection Agency, Office of Research and Development, EPA/600/R-04/121, www.epa.gov/nrmrl/pubs/600r04121/600r04121.htm	Three volume series provides guidance when selecting BMPs (either through retrofitting of existing BMPs or applying newly constructed BMPs to new development) to prevent or mitigate the adverse effects of urbanization
Infiltration vs. Surface Water Discharge: Guidance for Stormwater Managers, Final Report. 03-SW-4, Water Environment Research Foundation (WERF 2006)	Describes the performance of infiltration basins, bioretention, grass swales, porous pavement, as well as design and maintenance guidelines, and methods for modeling performance. Appendix D. Literature Review Supporting Design of Infiltration BMPs.
Maryland Stormwater Design Manual www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	Sizing and performance criteria for urban BMPs

Table 3-41. References on general stormwater treatment BMP type, effectiveness, and design approaches *(continued)*

Reference	Information provided
Stormwater Best Management Practices (BMP) Performance Analysis, December 2008, prepared for EPA by Tetra Tech	A procedure and results for estimating long-term performance for several types of LID BMPs designed and maintained in accordance with Massachusetts stormwater standards, but the procedure could be applied in other areas
Center for Watershed Protection Technical Memorandum: The Runoff Reduction Method www.cwp.org/Resource_Library/Center_Docs/SW/RRTechMemo.pdf	A framework for BMP designers to verify compliance with proposed stormwater regulations in Virginia
Water Environment Research Foundation. 2005b. *Performance and Whole-Life Costs of BMPs and SUDS* www.werf.org/AM/Template.cfm?Section=Search&Template=/CustomSource/Research/ResearchProfile.cfm&ReportId=01-CTS-21-TA&CFID=2715758&CFTOKEN=75805127	Research on stormwater BMP effectiveness and cost
International Stormwater Database www.bmpdatabase.org	Compendium of results from studies of BMP effectiveness
Technology Acceptance & Reciprocity Partnership (TARP)	Testing protocols and performance reports for manufactured pretreatment devices
Washington State Department of Ecology, *Evaluation of Emerging Stormwater Treatment Technologies* www.ecy.wa.gov/programs/wq/stormwater/newtech/index.html	Program for evaluating stormwater technologies proposed by vendors, and a clearinghouse for information and decisions on their use
Center for Watershed Protection's National Pollutant Removal Performance Database, Version 3 *www.cwp.org/Resource_Library/Center_Docs/SW/bmpwriteup_092007_v3.pdf*	Compendium of results from 166 studies of BMP effectiveness
Determining Urban Stormwater BMP Effectiveness http://books.google.com/books?id=p5qMMwofaDwC&lpg=PA175&ots=Z_1Tyw56OG&lr=&pg=PA175#v=onepage&q=&f=false (Strecker et al. 2000)	Discussion of protocols for measuring and reporting BMP effectiveness.
Design Approaches	
Chesapeake Stormwater Network's *Baywide Design Specifications* www.chesapeakestormwater.net/baywide-design-specifications2	Detailed design specifications for rooftop disconnection, filter strips, grass channels, soil compost amendments, green roofs, rain tanks, permeable pavers, infiltration, bioretention, dry swales, urban bioretention, filtering practices, constructed wetlands, wet ponds, and extended detention ponds
U.S. Department of Defense. 2004. *Unified Facilities Criteria (UFC) Low Impact Development* http://www.wbdg.org/ccb/NAVFAC/INTCRIT/ufc_3_210_10n.pdf	Design criteria and examples for LID practices

Table 3-41. References on general stormwater treatment BMP type, effectiveness, and design approaches *(continued)*

Reference	Information provided
City of Portland *2008 Stormwater Management Manual* www.portlandonline.com/BES/index.cfm?c=47952	Typical design details for a number of LID BMPs for urban settings
Strecker, E., M.M. Quigley, and B.R. Urbonas. 2000. Determining urban stormwater BMP effectiveness. In *Proceedings of the National Conference on Tools for Urban Water Resources,* February 7-10, 2000, Chicago, IL.	Overview of BMP effectiveness

Table 3-42 lists some of the design manuals that have a specific focus on treatment of nutrients; it is not intended to be a comprehensive list, and updates are routinely made as technology advances.

Table 3-42. Stormwater treatment design manuals or specifications with focus on nutrient removal for urban stormwater

Reference	Information provided
Developing Nitrogen, Phosphorus and Sediment Reduction Efficiencies for Tributary Strategy Practices, BMP Assessment Final Report www.chesapeakebay.net/marylandBMP.aspx (Simpson and Weammert 2009)	Effectiveness estimates, focusing on nutrients and sediment, for a number of urban, agricultural, and forestry BMPs
New York State Stormwater Management Design Manual, Chapter 10: Enhanced Phosphorus Removal Standards www.dec.ny.gov/chemical/29072.html	Phosphorus removal section recently added
Chesapeake Stormwater Network Baywide Design Standards (CSN 2010) www.chesapeakestormwater.net/all-things-stormwater/category/baywide-design-specifications	Specifications for 15 stormwater BMPs
New Jersey Stormwater Best Management Practices Manual www.state.nj.us/dep/stormwater/bmp_manual2.htm	Chapter 4 includes information on meeting nutrient removal performance standards, and Chapter 9 includes design standards
Northern Virginia BMP Handbook www.novaregion.org/DocumentView.aspx?DID=1679	BMP manual with design calculations for phosphorus removal
Virginia Stormwater BMP Clearinghouse www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html	BMP design specifications

The potential for trees and other vegetation to remove pollutants from stormwater as a treatment practice has been evaluated in phytoremediation research but has not yet been widely studied for applicability in sequestering pollutants removed from stormwater or for extending the life of bioretention media. Plants provide nutrient uptake, toxin uptake such as heavy metals, and pollutant breakdown. This is an area for future research. Resources for information on phytoremediation is included in Table 3-43.

Table 3-43. Resources for information on phytoremediation

Reference	Type of information
Phytotechnology Technical and Regulatory Guidance, The Interstate Technology & Regulatory Council 2009 (http://www.itrcweb.org/Documents/PHYTO-3.pdf)	Provides guidance on using vegetation for soil remediation, and estimates of transpiration rates
EPA's Brownfields Technology Primer: Selecting and Using Phytoremediation for Site Cleanup (http://www.clu-in.org/download/remed/phytoremprimer.pdf)	Phytoremediation process, advantages and considerations, and additional resources
Phytotechnology Project Profiles (http://www.clu-in.org/products/phyto/)	Case studies demonstrating phytotechnology applications

Assessing Treatment Technologies. Understanding unit operations and processes is necessary for success of the treatment system design, as well as system O&M. This modern approach for stormwater treatment is based more on traditional industrial drinking water and wastewater treatment concepts, rather than on traditional stormwater approaches that generally addressed only the more basic goal of removing total suspended solids. This approach is presented in *Critical Assessment of Stormwater Treatment and Control Selection Issues* (WERF 2005a) and is applicable as treatment concerns become more focused on removal of P and N. The approach advises users to first select unit operations or processes applicable for POCs on the basis of the pollutant form (i.e., dissolved, colloidal, particulate), chemical speciation (e.g., ionic metal species, P species), and granulometric characteristics (e.g., particle size, specific gravity, surface area), and then individually select the components of a treatment system according to the unit operations or processes that are effective for treating the POCs (see Table 3-44). For example, this approach is presented in the *New York State Stormwater Management Design Manual,* Chapter 10: Enhanced Phosphorus Removal Standards.

A benefit to the LID-approach for stormwater management, both infiltration/evapotranspiration and harvest and use such as in irrigation or in toilets, is that reduction of the runoff volume often translates to a runoff in pollutant loading, as well as the benefit of reducing the excess volumes of scouring, flash-flooding runoff.

Table 3-44. Unit operation or processes and typical treatment system components for fundamental process categories

Fundamental process category (FPC)	Unit operation or process (UOP) *Target Pollutants*	Typical treatment system components (TSSC)
Hydrologic Operations	Flow and Volume	Extended retention/detention ponds Wetlands Tanks/vaults Equalization basins
	Volume Reduction *All Pollutant loads*	Infiltration/exfiltration trenches and basins Permeable or porous pavement Bioretention cells Dry swales Dry well Extended detention basins
Physical Treatment Operations	Particle Size Alteration *Coarse sediment*	Comminutors (not common for stormwater) Mixers (not common for stormwater)
	Physical Sorption *Nutrients, metals, petroleum compounds*	Engineered media, granular activated carbon, and sand/gravel (at a lower capacity)
	Size Separation and Exclusion (screening and filtration) *Coarse sediment, trash, debris*	Screens/bars/trash racks Biofilters Permeable or porous pavement Infiltration/exfiltration trenches and basins Manufactured bioretention systems Engineered media/granular/sand/compost filters Hydrodynamic separators Catch basin inserts (i.e., surficial filters)
	Density, Gravity, Inertial Separation (grit separation, sedimentation, flotation and skimming, and clarification) *Sediment, trash, debris, oil and grease*	Extended detention basins Retention/detention ponds Wetlands Settling basins, tanks/vaults Swales with check dams Oil-water separators Hydrodynamic separators
	Aeration and Volatilization *Oxygen demand, PAHs, VOCs*	Sprinklers Aerators Mixers (not common for stormwater)
	Physical Agent Disinfection *Pathogens*	Shallow detention ponds Ultraviolet systems

Table 3-44. Unit operation or processes and typical treatment system components for fundamental process categories *(continued)*

Fundamental process category (FPC)	Unit operation or process (UOP) *Target Pollutants*	Typical treatment system components (TSSC)
Biological Processes	Microbially Mediated Transformation (can include oxidation, reduction, or facultative processes) *Metals, nutrients, organic pollutants*	Wetlands Bioretention systems Biofilters (and engineered bio-media filters) Retention ponds Media/sand/compost filters
	Uptake and Storage *Metals, nutrient, organic pollutants*	Wetlands/wetland channels Bioretention systems Biofilters Retention ponds
Chemical Processes	Chemical Sorption Processes *Metals, nutrients, organic pollutants*	Subsurface wetlands Engineered media/sand/compost filters Infiltration/exfiltration trenches and basins
	Coagulation/Flocculation *Fine sediment, nutrients*	Detention/retention ponds Coagulant/flocculant injection systems
	Ion Exchange *Metals, nutrients*	Engineered media, zeolites, peats, surface complexation media
	Chemical Disinfection *Pathogens*	Custom devices for mixing chlorine or aerating with ozone Advanced treatment systems

Source: WERF 2005a

Estimating Effectiveness of Stormwater Treatment Practices. As noted previously, estimates of the effectiveness of stormwater treatment practices vary for many reasons. The effectiveness of any stormwater BMP—for example, in annual pounds of pollutant removed or in percent of pollutant removed—will be a function of the rainfall pattern, the specific design of the BMP, the watershed and pollutant characteristics, and—for practices that include infiltration or filtration—the nature of the media. Media with high P or N content can export nutrients, while providing effective removals of trace metals. For more information on factors influencing the treatment effectiveness of bioretention and other LID practices, see the Fact Sheets.

A list of stormwater treatment BMPs, and their estimated effluent mean concentrations are provided in Table 3-45. The values are used in a WERF stormwater treatment model (the model name is SELECT) and provide an indication of the effluent quality that can be observed from the practices.

Table 3-45. Default effluent event mean concentration for BMPs used in WERF SELECT model

BMP	TSS (mg/L)		TP (mg/L)		TN (mg/L)	
	MED	**STD**	**MED**	**STD**	**MED**	**STD**
Extended Detention[a]	31	2	0.19	0.04	2.72	0.5
Wetland Basins[a]	18	1	0.14	0.02	1.15	0.2
Bioretention[a]	24	2	0.34	0.06	0.78	0.1
Swales[b]	13	1	0.22	0.05	2.72	0.4
Media Filters[a]	16	1	0.14	0.03	0.76	0.1
Permeable Pavement[a]	18	1	0.14	0.03	1.15	0.15

Source: Pomeroy and Rowney 2009

a. Geosyntec Consultants and Wright Water Engineers 2008.

b. Barrett et al. 1998

Estimates of potential pollutant-removal effectiveness were summarized on the basis of a literature review of data on the Chesapeake Bay watershed (*Recommendations for Endorsement by the Chesapeake Bay Program Nutrient Subcommittee and its Workgroups For use in Tributary Strategy Runs of Phase 5 of the Chesapeake Bay Program Watershed Model;* Collins et al. 2009, www.chesapeakebay.net/marylandbmp.aspx). The pollutant-removal estimates provided indicate that the majority of annual reduction in pollutant loading is derived from volume reduction, although some treatment can be achieved with appropriate media (low N and P content) and the conditions to enable denitrification to occur. Estimates of performance for LID practices, and other urban stormwater treatment practices, are provided for the following:

- Dry detention ponds and hydrodynamic structures BMPs
- Dry extended detention basins BMP
- Infiltration and filtration practices (includes bioretention, permeable pavement, infiltration trenches and basins, filters, and vegetated open channels)
- Urban wet ponds and wetlands

Infiltration and filtration practices have the best potential for addressing nutrient treatment of the because of the processes that can occur in the soils (if the soils are not nutrient-rich). LID technologies that do not provide *treatment* include green roofs, which provide volume reduction, and harvesting/blue roofs, which can provide volume reduction if flows are used for irrigation, other use, or can be evaporated. Note that infiltration through soils via applications such as bioretention are different from dry wells because a level of treatment is provided in the soil (see the 2008 EPA memorandum that clarifies that typical stormwater infiltration compared to dry wells, www.epa.gov/npdes/pubs/memo_gi_classvwells.pdf) (USEPA 2008a). The performance estimates for infiltration and filtration practices are provided in the Bioretention Fact Sheet in Appendix 1.

Actual pollutant-removal performance can vary significantly depending on many factors, including regional rainfall pattern, media specification, design features, and watershed characteristics that affect the pollutant concentration and speciation. To obtain more accurate estimates, approaches that combine pilot testing with continuous hydrologic modeling have been performed, for example in EPA Region 1. That type of approach could be successful in developing more accurate performance estimates for specific climate regions and practice designs (*Stormwater Best Management Practices (BMP) Performance Analysis,* prepared by Tetra Tech, Inc., for EPA Region 1 2008, www.epa.gov/region1/npdes/stormwater/assets/pdfs/BMP-Performance-Analysis-Report.pdf).

Long-Term Maintenance Considerations. Maintenance requirements should be evaluated as part of practice selection to help enable a more accurate comparison of the life-cycle costs of the practice. Maintenance considerations can include

- Necessary maintenance activities for the life of the control compared to alternatives
- How placement of the practice can affect maintenance (visibility, and such)
- Level of effort necessary to ensure adequate maintenance
- Frequency of maintenance necessary
- Responsible party to conduct maintenance or ensure continuing use of areas in drainage easements, and mechanisms for enforcement

Resources for information on maintenance considerations are provided in Table 3-46. Additional maintenance information is provided in the fact sheets in Appendix 1. Information on LID O&M costs is provided in Section 2 of this chapter.

Table 3-46. Resources for information on maintenance considerations

Stormwater Manager's Resource Center *Manual Builder* www.stormwatercenter.net	Information on maintenance tracking, frequencies, unit costs, easements, performance bonds, and checklists for maintenance inspections for common BMPs.
Virginia's *Maintaining Your BMP: A Guidebook for Private Owners and Operators in Northern Virginia* (VADCR 2009b) www.dcr.virginia.gov/chesapeake_bay_local_assistance/documents/bmpmaintfinal.pdf	Maintenance guidance for homeowners, homeowners associations, and other, nontechnical audiences.
Lake County, Illinois' *A Citizen's Guide to Maintaining Stormwater Best Management Practices for Homeowners Associations and Property Owners* www.northbarrington.org/files/newsletters/Guide_Final_110404.pdf	Step-by-step guide for planning for and conducting maintenance on common stormwater BMPs.
Pierce County, *Washington's Stormwater Maintenance Manual for Private Facilities* www.co.pierce.wa.us/xml/services/home/environ/water/wq/maintman/MaintManFinal2-22-05.pdf	Includes BMP-specific maintenance information and checklists as well as information on developing a maintenance program.

Physical Site Limitations. Physical site limitations can affect the appropriateness of a practice. These can include the following:

- Lack of adequate pervious area to infiltrate stormwater
- Presence of functionally impervious soils
- Steep slopes or a high groundwater table
- Presence of contaminated soils
- Potential for highly contaminated stormwater (from hotspots) infiltrating and contaminating groundwater source
- Proximity to building foundations, roadways, bridges, abutments, and retaining walls
- Lack of necessary vertical relief to transport stormwater flows
- Conflicts with underground utilities

Example resources for information on some of the site limitation issues are provided in Table 3-47.

Table 3-47. Example resources for information on some of the many site limitation issues to consider

Resource	Limitation addressed
CSN Technical Bulletin No. 1 *Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed Version 2.0,* Chesapeake Stormwater Network, Developed by Karst Working Group, Released June 2009	Infiltration practices in Karst areas
Groundwater Contamination Potential from Infiltration of Urban Stormwater Runoff. Shirley E. Clark, Robert Pitt, and Richard Field; To be published 2009 as Chapter 6 in *The Effects of Urbanization on Groundwater: An Engineering Case Based Approach for Sustainable Development.* Committee on Groundwater Hydrology, ASCE/EWRI.	Risk of groundwater contamination from infiltration practices
Center for Watershed Protection (CWP 2001) *Stormwater Practices for Cold Climates* www.stormwatercenter.net/Cold%20Climates/cold-climates.htm	Cold-climate considerations, including freezing temperatures and high runoff during snowmelt
Urban Small Sites Best Management Practice Manual, Chapter 2: Selecting BMPs (Metropolitan Council 2009) www.metrocouncil.org/environment/Water/BMP/manual.htm	Includes a matrix of physical feasibility factors to aid in selecting BMPs

Aesthetics and Safety. When selecting and designing BMPs, it is important to consider the surrounding land use type, the immediate context, and the proximity of the site to civic spaces to ensure that the site's aesthetics are preserved. Also, access to BMP areas should be limited to protect public safety. Finally, water should not be allowed to stand for longer than 72 hours to prevent mosquito breeding. More information about aesthetic and safety considerations is at the WERF *Using Rainwater to Grow Livable Communities* (WERF 2008b) site (www.werf.org/livablecommunities), particularly on the Green Infrastructure Design Considerations page (www.werf.org/livablecommunities/pdf/design.pdf).

4 Urban Runoff Management for the Redevelopment Sector

The implementation measures listed in Section 2 for reducing runoff volume are expanded in this section because of the importance of addressing redevelopment in the restoration of the Chesapeake Bay or other urban waterbodies.

The implementation measures specifically applicable to redevelopment (repeated from Section 2) are below.

Implementation Measure U-9 (in part):

Develop and implement redevelopment programs that identify opportunities for a range of types and sizes of redevelopment projects to mitigate water resource impacts that

- Establish appropriate redevelopment stormwater performance standards consistent with the goal of restoring predevelopment hydrology with regard to the temperature, rate, volume and duration of flow, or more restrictive if needed for site-specific water quality protection, as determined by the appropriate regulatory authority for the region or site.
- Include development of an inventory of appropriate mitigation practices (e.g., permeable pavement, infiltration practices, green roofs) that will be encouraged or required for implementation at redevelopment sites that are smaller than the applicability threshold
- Include site assessment to determine appropriate GI/LID practices
- Review facility planning documents and specifications (as well as any applicable codes and ordinances) and modify as appropriate to allow and encourage GI/LID practices
- Implement GI/LID demonstration projects
- Incentivize early adopters of GI/LID practices
- Maximize urban forest canopy to reduce runoff
- Conduct soil analyses and amend compacted urban soils to promote infiltration

About 50 percent of the residential, commercial, and industrial buildings present in the year 2030 will be constructed between 2000 and 2030 (Brookings Institute 2004), creating opportunities for water quality improvements that our cities must seize if we are to achieve the goals of restoring the Chesapeake Bay or other urban waters. As redevelopment projects occur over several decades, pollutant discharges from developed areas can be gradually reduced as practices are installed to incrementally improve the quality of runoff from existing, untreated developed land.

Sound redevelopment practices incorporate principles of smart growth and sustainable development (USEPA 2005c, 2006). LID practices installed at redevelopment projects in catchments that are served by combined sewer systems can help reduce the frequency and magnitude of CSOs to rivers and estuaries (Limnotech 2007).

Well-planned redevelopment is necessary for many reasons other than just water quality, prompting a growing number of redevelopment project designers and communities to develop holistic approaches for achieving water quality improvements in the redevelopment process in combination with other social, economic, and environmental factors. Water quality programs are an important component of a healthy, vibrant, livable, and environmentally sound community and are a key factor to consider in a redevelopment project.

Encouraging redevelopment, rather than greenfield development:

- Promotes land use efficiency
- Improves the quality of life in urban areas
- Optimizes use of existing public infrastructure
- Provides a tax base to enable maintenance of existing public infrastructure

LID and GI stormwater requirements create an excellent opportunity to facilitate mitigation of the effects of past development at the site or watershed scale, and to address other societal objectives.

Challenges and Opportunities in the Redevelopment Sector. Redevelopment projects require innovative, cost-effective, LID solutions to overcome challenges such as the following:

> *Site Constraints*. Most infill and redevelopment projects are small in area, highly impervious, and have existing utilities and infrastructure, all of which constrain the use of some traditional stormwater practices, particularly those that rely on infiltration through vegetative practices.

High Trash Loads. Runoff from highly urban watersheds is often severely polluted and contains a high load of trash, litter, debris and gross solids (City of Baltimore 2006), which can interfere with the performance of stormwater practices and creates the need for more frequent practice maintenance.

Compacted and Polluted Soils. Soils have been graded, eroded, and reworked by past development, often resulting in compaction such that runoff cannot be effectively infiltrated. In severe cases, legacy problems from past industrial and municipal activity have created *brownfields* that must be capped to prevent infiltration from leaching pollutants or contaminating soils (USEPA 2008b). For those sites with compacted or polluted soils, using infiltration practices might be limited. Example case studies are provided at EPA's Brownfields Program (http://www.epa.gov/brownfields/tools/swcs0408.pdf) (USEPA 2008c).

Natural Stream Network is Altered or Buried. Urbanization has severely altered, reduced or eliminated the natural stream network (National Research Council 2008). The urban stream system that remains is often highly degraded and altered in size and shape, and most development projects discharge to existing storm drain pipes or conveyance channels rather than streams.

Feasibility and Cost of Compliance. The cost of stormwater practices at redevelopment projects in highly urban settings is often more expensive than in new development projects in greenfield settings, where more surface land is available for the practices (Schueler 2007). The potential exists for other types of cost savings or amenity benefits, and they should be considered in addition to capital cost comparisons (Portland BES 2007).

Redevelopment Should Focus on Both Source Control (Pollution Prevention) and LID. Redevelopment sites in the Chesapeake Bay watershed and elsewhere in the nation often discharge to receiving waters that are listed as water quality impaired and require pollutant reductions through TMDLs for a range of pollutants, including bacteria, trash, nutrients, metals and hydrocarbons. All these varied sources should be addressed in redevelopment.

Smart Growth Considerations. Integrating LID practices into high-density land development is an essential element of creating desirable smart growth communities with green infrastructure, and sustainable cities, but it can be a challenge, especially for designers and developers unfamiliar with the practices. Therefore, it is important that managers select stormwater practices that will be consistent with those important redevelopment principles.

Because of those constraints, many urban communities in the Chesapeake Bay watershed (and elsewhere in the nation) have historically waived, relaxed, or otherwise reduced stormwater requirements for redevelopment projects. That has contributed to the continuing deterioration of urban waters. However, in recent years, stormwater managers have taken a more creative approach to treating stormwater from the redevelopment sector (see Figure 3-22 for example) that reflects the following opportunities:

> *New Redevelopment Practices*. In the past decade, considerable research has been conducted, demonstrations made, and experience gained—all of which demonstrate that a variety of LID practices can be used that are specifically adapted for highly urban areas. Those include practices such as expanded tree boxes with supporting structures to prevent soil compression under pavements, green roofs, permeable pavements, and flexible rubber sidewalk sections allowing for less destructive tree root growth). The new practices emphasize the sustainable use of stormwater as part of green buildings and green infrastructure. In addition, the new practices promote larger sustainability objectives such as increased energy efficiency and water conservation, greater building longevity, community greening, safer and more walkable communities, cleaner and cooler air in the summer, habitat for birds, and more creative architectural solutions.
>
> *Green Building and Sustainability Movement*. Designers are seeking *green* certifications for their buildings, and points are awarded for using innovative stormwater practices. Other certification systems reward effective stormwater solutions for the entire site and not just the building itself. Together, such certification systems provide powerful incentives to create innovative stormwater solutions for redevelopment projects.
>
> *Municipal Leadership on Green Infrastructure*. Federal facilities can look to cities that have found that a green approach to designing their streets, parking lots, and buildings can provide multiple benefits in the urban setting, and have retrofitted their infrastructure designs and building codes to allow for green streets and streetscapes, urban forestry, and landscaping areas to treat stormwater (City of Emeryville 2005; City of Philadelphia 2008; City of Portland 2008b; San Mateo County 2009).

With CSO abatement costs expected into the billions, in 1996 the Philadelphia Water Department (PWD), determined that after implementing conventional solutions, local waterways would still have eroded banks poor water quality and habitat. PWD decided to simultaneously address CSOs, the stormwater permit, Clean Drinking Water Act requirements, and repeated flooding, while preserving watershed health. Their strategy targets the sources of urban runoff and water quality problems rather than just symptoms. Philadelphia is focusing on

- A performance-based stormwater ordinance to create incentives for BMP use
- Pilot BMPs for research and education
- A stormwater rate reallocation study to migrate to an impervious-area-based formula

The ordinance encourages a return to predevelopment conditions requiring developers to manage the first inch of stormwater on-site. PWD partnered with other city departments to set up a new development review process. At one time PWD was the last to see development plans, now they are among the first, so they can request changes in designs to accommodate water quality goals before plans are finalized.

The building industry would have more requirements with the new regulations, but the city knew that these were not so different from what they face with greenfield development. The development community could be creative and use combinations of practices to meet the water quality, CSO abatement, and flood control requirements. So many requirements exist for development of green space, that infill development in Philadelphia is easier than in suburban areas.

Some chaos ensued in the first three months of the new ordinance, with pushback from developers and city agencies. Waivers were requested, none were granted. Only a small fraction resorted to in-kind trades implementing BMPs offsite but in the same sewershed. One year and approximately 500 development plans later, the city has seen a significant change in the regulated community. Developers learned which firms adapted to the requirements and can sail through review. There has been a substantial decrease in resubmissions.

The green development *buzz* spread. Developers realized that these BMPs offer benefits beyond stormwater control, and they are trying innovative approaches on their own as part of the trend to build more sustainable (e.g., LEED-certified) buildings. Recently, a public housing authority chose to install porous pavement because it was comparably priced and would allow for smaller drainage pipes. Infill developers garner support for a project by highlighting the potential to reduce neighborhood flooding, as the new requirements *turn back the clock* and improve on predevelopment conditions.

Demonstrating the Benefits of Green Infrastructure BMPs. How do these practices benefit rate payers? PWD showed quantitatively how the approaches help maintain streams and support more conventional infrastructure. They demonstrated cost benefits: each dollar spent on green practices resulted in a tangible improvement. Specifically, staff showed that the stormwater rate reallocation was estimated to alleviate the need for tanks that control 40 million gallons of stormwater, offering a direct financial benefit to the city. All of these efforts gradually changed the image of an institution that historically has been more comfortable with more engineered solutions. Now city officials come to PWD with green ideas of their own.

Future Expectations for the Successful Redevelopment Program. The city expects that charges to residential customers would remain the same or decrease, whereas charges to commercial customers would increase somewhat, as would be expected based on the relative amounts of impervious surface. The city provides other financial incentives, as well, such as a new tax credit for green roofs. Over the long term, the city expects that the stormwater fee will encourage more BMP implementation. They hope that businesses and institutions will consider the balance between initial capital costs for installing a BMP with the reduction over the long term in the rate charged for the stormwater utility.

PWD's staff enjoys the praise they receive from the community on individual projects and from other cities who want to learn from their successes. They are pleased that the development community has embraced the new stormwater regulations and have started to take the initiative in implementing green solutions.

Source: Adapted from the Water Environment Federation *Livable Communities*
http://www.werf.org/livablecommunities

Figure 3-22. Philadelphia: A successful redevelopment approach to restoring water quality, using a municipal example, shows how standards to manage stormwater on-site are accepted into facility planning approaches.

4.1 Establish Stormwater Performance Standards for the Redevelopment Sector Consistent with the Goal of Restoring Predevelopment Hydrology

For all redevelopment sites, establish the means of determining compliance with the performance standard for runoff volume reduction or pollutant reduction. The federal government is leading by example by requiring runoff volume reduction that would either be equivalent to that of predevelopment hydrology, or as a default depth, from the 95th percentile rainfall event. That requirement applies for redevelopment projects at federal facilities and lands nationwide, and is described in U.S. DoD (2009) and USEPA (2009e). It is derived from section 438 of the 2008 Energy Independence and Security Act. In the Chesapeake Bay watershed, that LID requirement would apply to about 1.5 to 1.9 inches of rainfall, depending on where the project is in the watershed.

4.2 Stormwater Management Practices for Redevelopment

A unique set of practices are commonly used to reduce runoff and pollutant loads from the redevelopment sector, as shown in Table 3-48. The practices can be applied to address untreated impervious or pervious areas in the redevelopment sector.

Table 3-48: Example practices for addressing the redevelopment sector

Treat impervious cover	Manage pervious areas
Green Roofs Rainwater Harvesting, including Blue Roofs Foundation Planters Permeable Pavers Expanded, Compaction-protected Tree Pits Flexible Rubber Sidewalk Sections for Tree Pits Urban Bioretention Bioretention	Conserve and Restore Natural area Remnants Soil Amendment and Restoration Reforestation Conservation Landscaping Turf Management Impervious Cover Reduction Create Functional Bioretention from Elevated Parking Lot Islands and Traffic Medians

Note: Where surface area is available, typical on-site LID stormwater practices from the new development sector can be used. In addition, when feasible on-site practices are not capable of achieving full attainment of predevelopment hydrology, restoration practices from the existing development areas may help in mitigation. For more detailed information on each practice, see the practice profile sheets in Appendix 1 of this chapter.

Key considerations in applying these practices are as follows:

- *Use a Roof to Street Design Approach*. Break the site into smaller drainage areas with a unique LID solution for each area (e.g., roofs, pedestrian areas, streets, open space and parking lots). In that manner, stormwater management is directly integrated into the design of buildings, parking lots, hardscapes, open spaces, landscaping, and streetscapes. That avoids the need for underground structures or consumption of costly surface real estate for stormwater practices. The basic approach includes

- Managing rooftop runoff through green roofs, water harvesting, disconnection, or storage and release from foundation planters
- Minimizing surface parking or designing surface parking to reduce, store, and treat stormwater using permeable pavements, bioretention, or biofiltration (see San Mateo County 2009)
- Designing urban hardscapes such as plazas, courtyards, and pedestrian areas to store, filter, and treat runoff using permeable pavers (with storage in the void space of underlying gravel), stormwater planters, and amenity bioretention areas
- Ensuring that all pervious and landscaping areas in the redevelopment project are designed for effective stormwater treatment using practices such as soil restoration, reforestation, and bioretention
- Designing the streetscape to maximize the capture and use of stormwater runoff by using expanded tree pits, street bioretention, curb cut extensions, and other *green street* methods (see City of Portland 2008b; City of Philadelphia 2008; and San Mateo County 2009)

An example of such a design approach is the redevelopment of an office building at 1050 K Street, NW, Washington, DC, in the downtown business district, shown in Figure 3-23. Figures 3-24 and 3-25 provide additional redevelopment examples.

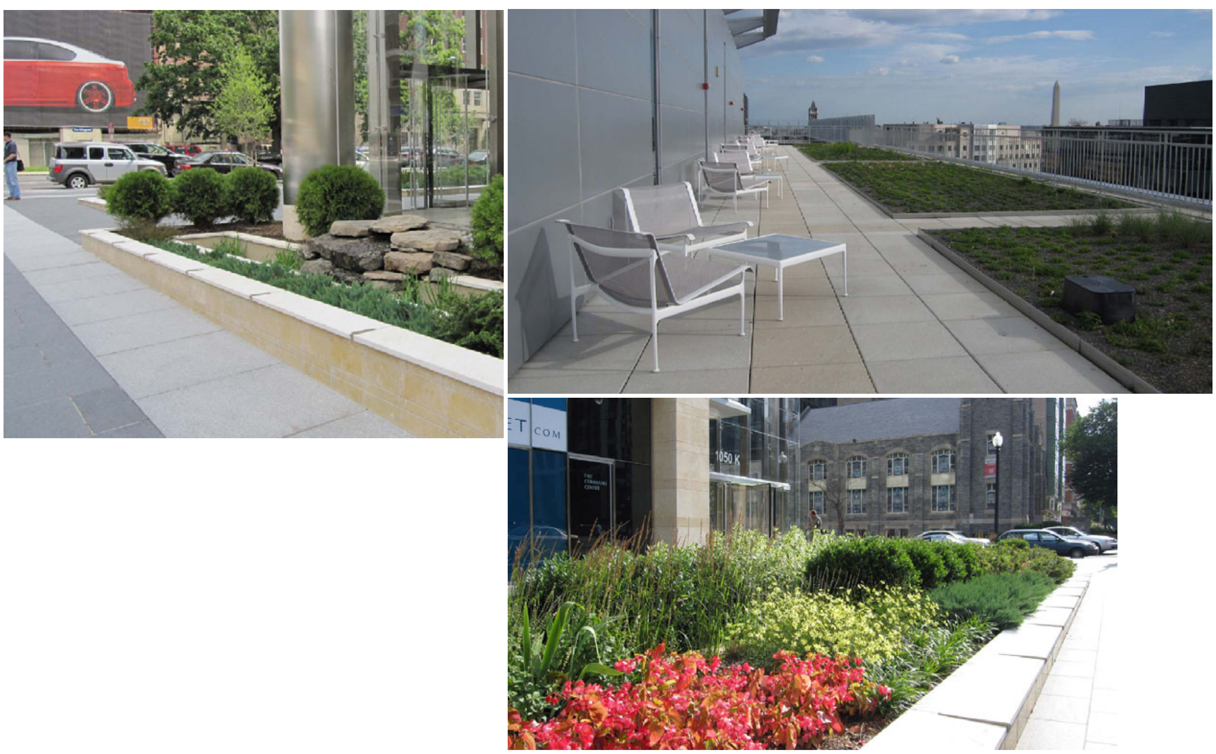
- *Reduce Real Impervious Cover*. Ensure that pervious cover performs hydrologically as if it were an undisturbed pervious area. Deep tilling and amending soils with compost and other materials can increase porosity and water holding capacity. In many cases, runoff from rooftops can be effectively disconnected and drained over such *improved* pervious areas.
- *Identify and Treat Hotspot-Generating Areas*. Require that contributing drainage areas from stormwater *hotspots* be isolated from the remainder of the site (usually by grading and drainage) so that the runoff can be fully treated to prevent toxic discharges to surface water or groundwater.
- *Adapt LID to Urban Design*. Adapt principles such as Better Site Design (CWP 1998) to urban environments. Examples include innovative urban parking management solutions (City of Emeryville 2005), municipal green street specifications (San Mateo County 2009), context-sensitive road design standards providing stormwater treatment in the right-of-way (MC 2008), and modifications to traditional streetscape standards to use

street trees as a stormwater filtering device (City of Portland 2008b; Cappiella et al. 2006; *Stormwater Magazine* March/April 2010).

The potential for green infrastructure to mimic natural systems even in the densest cities is demonstrated at 1050 K Street—a LEED Gold-certified office building in the heart of Washington, DC, on the site of a former parking lot. The site had been 97 percent impervious. The project design reduced impervious area to 67 percent. Runoff from the property occurs only in a major storm event because of the green infrastructure practices employed in the building design:

- Two tiers of green roofs retain rainwater falling on the rooftop
- Three bioretention cells in the building plaza retain and treat runoff from adjacent impervious areas
- A 5,000-gallon cistern beneath the building complements these features by storing any stormwater that cannot be retained.
- All irrigation water is from the cistern, reducing building water consumption and maintaining cistern storage capacity.

This suite of green infrastructure practices provides stormwater benefits, an urban oasis for the tenants and passers-by, and a competitive advantage for the building owners (Lanier 2007).



Photos, courtesy Lu Gay Lanier, The Timmons Group

Figure 3-23. Redevelopment stormwater retrofits at 1050 K Street, Washington, DC, illustrates practices applicable to federal facilities.

In 2009 Manassas Park, Virginia, expanded the elementary school, using an existing impervious parking lot as the site. The new school incorporates many natural educational features, a historic site, and functional stormwater features. Native plants and no-mow meadow grasses are used to enhance the educational experience. The post-development runoff is slightly lower than predevelopment conditions. See a video highlighting the features at http://vimeo.com/chesapeakebay.

A 75,000-gallon rainwater cistern, built to potable water standards, collects rainwater from the entire rooftop area and is used for toilet flushing and irrigation. It is estimated to conserve 1.3 million gallons of water per year. An outdoor classroom with semicircular, stepped seating doubles as a stormwater bioretention cell.

Figure 3-24. Manassas Park Elementary School.

The Yorktown retrofit project serves as a model for residential and business communities demonstrating how green roofs and other stormwater management designs can be implemented to improve water quality, decrease erosive stormwater, and conserve flora and wildlife resources in the Chesapeake Bay watershed.

In designing the green roof, structural concerns relative to the 30-year-old building were a major factor in the decision to use a lightweight building system incorporating waterproofing, root barrier, water retention, and drainage system in one layer. The 15 pound/square foot capacity had to include all weight associated with the waterproofing, growing media, water retention system, and mature vegetation (fully saturated and fully hydrated). The project, including membranes cost $12 per square foot (sf) (for a 4,700-sf green roof system).

It is estimated that the green roof provides a 20 percent reduction in cooling cost and should enjoy a life expectancy of more than 40 years. Initial reports confirm that 80 percent of the annual rainfall is retained on the roof, via a hydrogel technology along with the design of the porous growing media. Other storm water management features consist of rain gardens, a bioswale, and a federally protected biohabitat.

Source: www.greenroofs.org/washington/index.php?page=yorktown

Figure 3-25. Yorktown Square Condominiums, Falls Church, Virginia, successfully implemented a green roof retrofit.

4.2.1 Practice Integration and Assessment Tools

Effective application of the roof-to-street design approach in the redevelopment sector requires creative integration of stormwater practices in buildings, courtyards, streetscapes, and parking lots. Multiple practices are used to treat and reduce runoff from small and different urban surfaces, using a treatment train approach to help ensure the best performance. Redevelopment programs should identify opportunities for a range of types and sizes of redevelopment projects. Practices should be identified that can be encouraged or required for implementation at sites even below applicability area thresholds.

Integrating stormwater management practices into design requires overcoming some of the development *silos* that focus on a single-purpose objective. Landscaping can be designed as functional; parking lots can be designed with drainage features enabling placement of bioretention; opportunities have been identified in many formerly single-use designs.

Several tools have been developed to track progress in meeting the performance standards for the redevelopment sector, and to identify cost-effective combinations of practices at the site. Such tools include the following:

- A series of spreadsheets that allow the user to break the site into smaller drainage areas and size and optimize the most appropriate practices for them. For example Emeryville, California (City of Emeryville 2005), developed a spreadsheet-based calculator to determine the proper size of stormwater treatment devices for new development projects (see http://ca-emeryville.civicplus.com/DocumentView.aspx?DID=109). Virginia Department of Conservation and Recreation (VA DCR 2009a) developed a spreadsheet-based tool to estimate stormwater volume reduction and pollutant removal (see www.dcr.virginia.gov/lr2f.shtml).
- Philadelphia uses a series of checklists and worksheets to achieve the same purposes (City of Philadelphia 2008) (see www.phillyriverinfo.org/PWDDevelopmentReview/RequirementsLibrary.aspx#)

Urban communities in the Chesapeake Bay watershed and elsewhere should adapt and modify such integration tools to meet their unique redevelopment conditions.

Designers might also maximize stormwater *green* points to obtain green building certifications or use the performance benchmarks for sustainable stormwater initiatives (ASLA 2009). See the example in Figure 3-26.

The Eastern Village Condominiums structure is a redevelopment of a former office building that has been transformed into 56 condominium units in a thriving urban community. It is the first LEED-certified cohousing structure. Before construction, the site was more than 90 percent impervious while the new design decreased the imperviousness of the site to 54 percent. Practices installed at the site include a green roof, a vegetated courtyard, and rain barrels.

Roof area: 12,330 sf

Planted area: 8,000 sf

Cost: $36/sf (2006)

Source: www.greenroofs.org/boston/index.php?page=easternwin

Figure 3-26. Eastern Village Cohousing Condominiums HOA, Silver Spring, Maryland, are an example of redevelopment with stormwater management and amenity value from a green roof.

4.3 Site Evaluations

Site evaluations should be conducted to determine the appropriateness of infiltration practices. Soils should be evaluated to determine whether the site is subject to brownfield remediation. Stormwater designers can use the assessments to determine if stormwater runoff can be infiltrated, soils need to be capped, environmental and utility constraints exist, or natural area remnants can be protected or restored. The investigations are also useful to map the best locations for LID practices and how they can be connected as an effective system.

4.4 Planning Documents and Specification Review

Change or supplement planning documents and specifications as necessary to allow the use of certain redevelopment practices (e.g., rainwater harvesting/plumbing codes, green roofs/building codes; green streets/road codes). Some issues that federal facilities deal with are similar to codes and ordinances of local government, and those local government requirements could affect facility planning and design. Examples of municipal guides for codes review to help overcome barriers to LID implementation are EPA's *Water Quality Scorecard* (http://cfpub.epa.gov/npdes/greeninfrastructure/munichandbook.cfm) (USEPA 2009f), *Better Site Design: A Handbook for Changing Development Rules in Your Community* (CWP 1998) and NRDC's *Out of the Gutter: Reducing Polluted Runoff in the District of Columbia* (Woodworth 2002) (www.nrdc.org/water/pollution/gutter/gutter.pdf).

4.5 Demonstration Projects

Implement demonstration projects to promote and demonstrate green infrastructure techniques. That approach is proven to promote progress in implementing innovative practices.

4.6 Incentives for Early Adopters

EPA provides examples of program types and municipal case studies in the *Managing Wet Weather with Green Infrastructure Municipal Handbook Incentive Mechanisms* (USEPA 2009a). For municipalities, those can include a wide variety of financial and fee-reduction incentives.

For federal facilities, incentives include awards and recognition programs. In addition, when land is leased to private entities, requirements for on-site stormwater management should be included where technically feasible.

4.7 Maximize Urban Forest Canopy

Maximize vegetation and forest canopy across the site to gain incremental stormwater treatment using expanded tree pits, green roofs, foundation planters, and urban bioretention. Information on urban forestry practices is in section 2.8.1, and in the fact sheet on reforestation/urban forestry in Appendix 1.

4.8 Amend Compacted Urban Soils

Urban soils are often compacted resulting in poor infiltration rates. Amending the soil with compost or another soil mixture can significantly increase the infiltration rate for the soils. Information on soil amendment practices are in Section 5 on turf management, and in the fact sheet on soil amendment in Appendix 1. Soil amendments can export N and P, in particular just after installation, so take care to ensure use of low-P-containing soils, and to not offset the benefit of stormwater retention with nutrient export in larger storm events.

5 Turf Management

This section provides guidance on recommended turfgrass management practices that can be used to reduce the impacts of developed and developing areas on water quality. It provides recommendations that address both the initial design of landscapes and management practices that apply to the long-term management of areas planted with turf. Several overall principles guide the development of an effective turf management program.

Ideally, landscapes should be designed to achieve multiple goals, e.g., recreational use, aesthetics, wildlife habitat, water quality, and public health benefits. Designers should consider desired end uses, site conditions, maintenance needs, and potential benefits and other impacts that could result from a given design or set of landscape designs. The design and maintenance of a landscape, whether it is covered by turf or other vegetation, requires the use of an adaptive management approach that should be periodically adjusted according to the original vision for the landscape, changing site conditions, and other factors such as changes in use, local codes, and ordinances and other societal values that can dictate the desired use of the landscape.

For example, municipalities around the United States are implementing green infrastructure programs to modify both the built environment and the associated landscapes to reduce stormwater runoff, urban heat island impacts, air pollution, maintenance costs, and energy consumption. To simultaneously achieve those goals, many cities and private entities are actively trying to promote integrated designs that are more sustainable in the long term, less costly to maintain, more resilient to change, and provide higher levels of environmental protection and improved community livability.

The use of turf in landscapes has a longstanding history and is desirable in many situations for playing fields, access to facilities, safe transportation routes, urban open/green spaces, runoff filtration, and the like. However, all turf does not function equally in terms of use and performance, nor is turf the optimal vegetative cover for all landscape applications in terms of water quality protection. This section provides recommendations on how to manage different categories of turf on the basis of management prescription and environmental performance from a water quality and hydrologic perspective.

The following list of implementation measures provides an overview of the approaches and practices recommended in this section. For purposes of this section, *turf* refers primarily to grass grown on lawns and other landscaped areas in suburban and urban areas and not specifically to sod farms. (Although sod farms are not the focus of this guidance, the turf area cover and distribution numbers developed by the Chesapeake Stormwater Network include turf area cultivated by sod farms in the Chesapeake Bay watershed. For more detail, see Table 3-49.)

Implementation Measures:

Turf Landscape Planning and Design

U-18. Where turf use is *essential* and appropriate, turf areas should be designed to maintain or restore the natural hydrologic functions of the site and promote sheet flow, disconnection of impervious areas, infiltration, and evapotranspiration.

Turf Management

U-19. Use management approaches and practices to reduce runoff of pollutant loadings into surface and ground waters.

U-20. Manage turf to reduce runoff by increasing the infiltrative and water retention capacity of the landscape to appropriate levels to prevent pollutant discharges and erosion.

U-21. Manage applications of nutrients to minimize runoff of nutrients into surface and ground waters and to promote healthy turf

- Where appropriate, consider modifications to operations, procedures, contract specifications and other relevant purchasing orders, and facility management guidance to reduce or eliminate the use of fertilizers containing P

U-22. Manage turf and other vegetated areas to maximize sediment and nutrient retention.

U-23. Reduce total turf area that is maintained under high-input management programs that is not essential for heavy use situations, e.g., sports fields and heavily trafficked areas.

U-24. Convert *nonessential*, high-input turf to low-input or lower maintenance turf or vegetated areas that require little or no inputs and provide equal or improved protection of water quality.

U-25. Use turf species that reduce the need for chemical maintenance and watering, and encourage infiltration through deep root development.

U-26. Conduct a facility or municipal wide assessment of the landscaped area within the facility property or jurisdiction. This assessment should include

- A map of the jurisdiction or facility, including the identification of all turf and other landscape areas

- An inventory or calculation of the total turf and other landscape area in acres or hectares using GIS techniques or other methods
- An evaluation to determine essential and nonessential turf areas
- Identification and delineation of all high-input, low-input, and no-input turf areas
- An evaluation of turf management activities and inputs, preferably by turf category or significant turf area within the facility or jurisdiction
- An assessment of landscape cover type benefits such as pollution load reductions and resource savings, e.g., water and energy that are provided by each landscape cover type
- An assessment of landscape cover type health, infiltrative and pollutant loading capacity and opportunities to increase soil health to promote the infiltrative capacity of turf and landscape areas
- An assessment of surface water and groundwater loadings related to high-input, low-input, and no-input turf area

U-27. Develop a management plan that contains

- An analysis of options to reduce or eliminate *nonessential* turf or convert *essential* turf to low-input turf that performs optimally from a water resource protection perspective
- An analysis of turf areas to identify opportunities to maximize water quality benefits of landscapes in regard to runoff, in-stream flows, infiltration, groundwater recharge and sediment, nutrient and pathogen loadings
- A landscaping approach that integrates turf management within the context of natural resource and habitat plans
- Stated goals and objectives regarding the reduction of turf related inputs (water, fertilizers, pesticides, fossil fuels) and maximizing water resource benefits on a facility- or municipality-wide basis
- An analysis of options to reduce potable water use by using cultural practices, hardy cultivars, or recycled water or harvested runoff
- An identification of areas where soil amendments can be used to enhance soil health and the infiltration capacity of the soils
- Areas of turf that could be used to manage runoff
- Areas of turf that could be replaced by lower maintenance cultivars or other grasses such as switch grass

- A training program for landscaping personnel
- An implementation schedule
- An annual landscaping inventory and progress report

U-28. Develop and implement ongoing public education and outreach programs Bay-friendly lawn, landscape, and turf management. Programs should target behavior change and promote the adoption of water quality friendly practices by increasing awareness, promoting appropriate behaviors and actions, providing training and incentives. Impact and effectiveness evaluation should be incorporated into such outreach and education programs.

5.1 Background

In the Chesapeake Bay watershed, turf has been estimated to cover 3.8 million acres or 9.5 percent of the total land area. Turf, in terms of total area, is now the number one cultivated ground cover grown in the Chesapeake Bay watershed (Chesapeake Stormwater Network 2010). Tables 3-49, 3-50, and 3-51 adapted from the Chesapeake Stormwater Network (2010) reflect estimates of turf cover by state, distribution by landscape category or sector, and by county with the highest turf density. Figure 3-27 illustrates turf density by county in the Chesapeake Bay watershed that appears to show a positive relationship between degree of urbanization and turf cover density.

Table 3-49. Year 2001 turf cover estimate using a GIS and satellite data

State	Land acres in bay watershed	Urban[a] turf acres	Exurban[b] turf acres	Total turf acres	Percent land area with turf
MD	5,639,428	1,007,269	298,476	1,305,745	23.15%
VA	13,706,037	988,291	135,792	1,124,083	8.20%
PA	14,345,262	900,803	158,212	1,059,015	7.38%
DC	38,956	16,071	2,320	18,391	47.21%
DE	450,384	31,337	3,648	34,985	7.77%
NY	3,983,079	160,788	32,982	193,770	4.86%
WV	2,288,363	75,515	12,425	87,940	3.84%
Total	40,451,509	3,180,074	643,855	3,823,929	9.45%

Source: Chesapeake Stormwater Network 2010.

a. Urban area includes impervious and non-forested pervious surfaces in industrial, commercial, and residential areas with lot sizes generally less than 2 acres.

b. Exurban areas represent all non-urban lands. The *urban recreational grass* land cover class was solely used to identify turf grass in exurban areas.

Table 3-50. Distribution of turf grass by sector in Maryland, Virginia and New York (percent)

Turf sector	1989–1998[a]	MD 2005	VA 2004	NY 2005
Home lawns	70	82.6	61.6	82.1
Apartments	nd[b]	0.6	nd	0.8
Roadside Right-of-Way	10	4.3	17.5	nd
Municipal Open Space	7	3.5	6	nd
Parks	3.5	1.9	2.5	1.9
Commercial	nd	nd	5	0.3
Schools	3	3.4	2.9	1.6
Golf Course	2.5	1.4	2.2	3
Churches/Cemeteries	2	1.2	1.4	1.1
Airports/Sod farms)	1	1.1	0.9	0.6

Source: MDASS 2006, VADACS 2006, and NYASS 2004, as reported in Chesapeake Stormwater Network 2010.

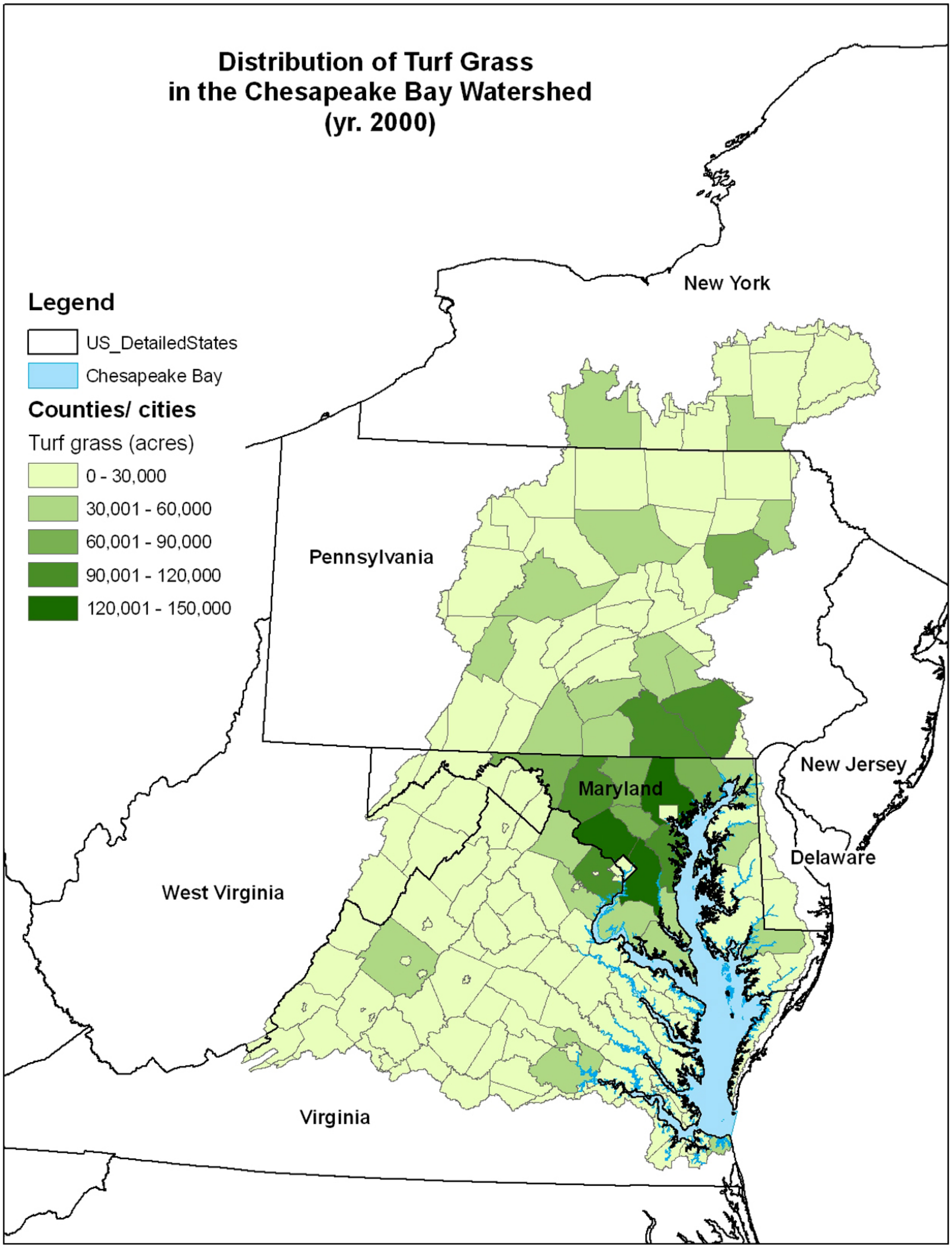
a. Average of three states: MDASS (1996), VAASS (1998) and PAASS (1989)

b. nd = no data because the indicated turf sector was not sampled or estimated

Table 3-51. Counties in the Bay watershed with the highest turf grass cover based on GIS

Jurisdiction/county	State	Turf acres	Total land acres	Percent turf
Montgomery	Maryland	140,272	317,420	44.20%
Baltimore	Maryland	136,456	379,708	35.90%
Prince George's	Maryland	121,008	306,846	39.40%
Lancaster	Pennsylvania	119,615	605,215	19.80%
Fairfax	Virginia	116,932	251,360	46.50%
York	Pennsylvania	110,564	577,749	19.10%
Frederick	Maryland	96,309	424,381	22.70%
Anne Arundel	Maryland	93,081	260,832	35.70%
Carroll	Maryland	85,114	286,896	29.70%
Harford	Maryland	77,084	272,524	28.30%
Howard	Maryland	66,239	160,906	41.20%
Luzerne	Pennsylvania	63,887	486,405	13.10%
Washington	Maryland	61,527	295,043	20.90%
Dauphin	Pennsylvania	56,347	337,650	16.70%
Henrico	Virginia	55,643	150,305	37.00%

Source: Chesapeake Stormwater Network 2010.



Source: Chesapeake Stormwater Network 2010

Figure 3-27. Distribution of counties with high turf cover in the Chesapeake Bay watershed.

The increase in turf area reflects a national trend according to Robbins and Birkenholt (2001) who examined turf in terms of land use/cover changes and the "expansion of high-input, monocultural, lawn landscapes," that "bring with them inputs of insecticides, herbicides and fertilizers...expanded use of lawn maintenance tools" such as mowers and "changes in soil profile, stormwater runoff, water consumption, micro-fauna diversity, energy use, air quality and habitat impacts." Fender (2008) reported that nationally, "There are an estimated 50 million acres of maintained turfgrass in the United States on home lawns, golf courses, sports fields, parks, playgrounds, cemeteries, and highway rights-of-way." Milesi et al. (2005) reported that nationally, 15.8 million acres (31.6 percent) of cultivated turf is in home lawns.

Turf that is properly located, selected, and maintained can provide water quality benefits, especially when used to reduce the effects of impervious surface cover (Beard and Green 1994; Carrow et al. 2008). As noted earlier in Sections 1–3 of this chapter, the use of practices that can reduce the effective impervious surface area of a developed area is encouraged. Landscapes planted with turf can effectively be used to treat runoff in grassed swales and filter strips and are commonly used along transportation systems and the borders of agricultural lands to reduce runoff pollutant loadings. Schueler (1987) described how such grassed systems can be designed for the catchment and filtration of runoff. For more information regarding the benefits of grass swales to manage runoff from agricultural fields, see Chapter 2. Grass swales also have proven to be effective in treating pollutants in highway runoff (Davis 2009).

The conversion of native landscape to turf, however, inevitably results in ecosystem-level changes regardless of how the turf is managed. For example, the conversion of native forest or native vegetation to turf or other cultivated landscapes can cause reductions in evapotranspiration; increases in runoff volumes, velocities and duration of flows; increases in runoff temperature; microclimate changes; decreased infiltration; changes in soil health and biota; and loss of species diversity and habitat. Infiltration tests conducted in a North Carolina watershed found that a medium-aged, pine-mixed hardwood forest has a mean final constant infiltration rate of 12.4 inches per hour; however, when the forest understory and leaf litter were removed, the resultant lawn had a mean infiltration rate of 4.4 inches per hour (Kays 1980). Dierks (2007) discussed the hydrologic benefits of native landscapes in his publication *Not all Green Space is Created Equal* and made the point that the heterogeneous nature of native landscapes typically results in stable ecological systems that do not require the level of inputs that managed turf typically requires. Dierks used Table 3-52 (adapted from Bharati 2002) and Figure 3-28 to emphasize the benefits of native landscapes and to compare the differences in hourly infiltration rates of different vegetative cover types such as silver maples and switch grasses and the differences in grass root depth and structure between native grasses and Kentucky bluegrass. Note, however, that changes in infiltration rate and soil health also can be due to land disturbances that occur during the development process. Typical land clearing practices often strip fragile topsoils from the site and compact the subsoils. In such situations, soil amendments can be used to restore soil health, and turf is often an appropriate cover to prevent erosion and reduce runoff related problems.

Table 3-52. Average hourly infiltration rates from multispecies buffer (adapted from Bharati et al. 2002)

Treatment	Jun	Aug	Oct/Nov	Avg
(cm/hr)				
Silver Maple	38	46	30	38
Grass Filter	29	20	25	25
Switchgrass	27	8	21	19
Bean	8	9	13	10
Corn	3	5	3	4
Pasture	2	4	3	3
Sandy Loam				1.1*
Silty Clay Loam				0.3*

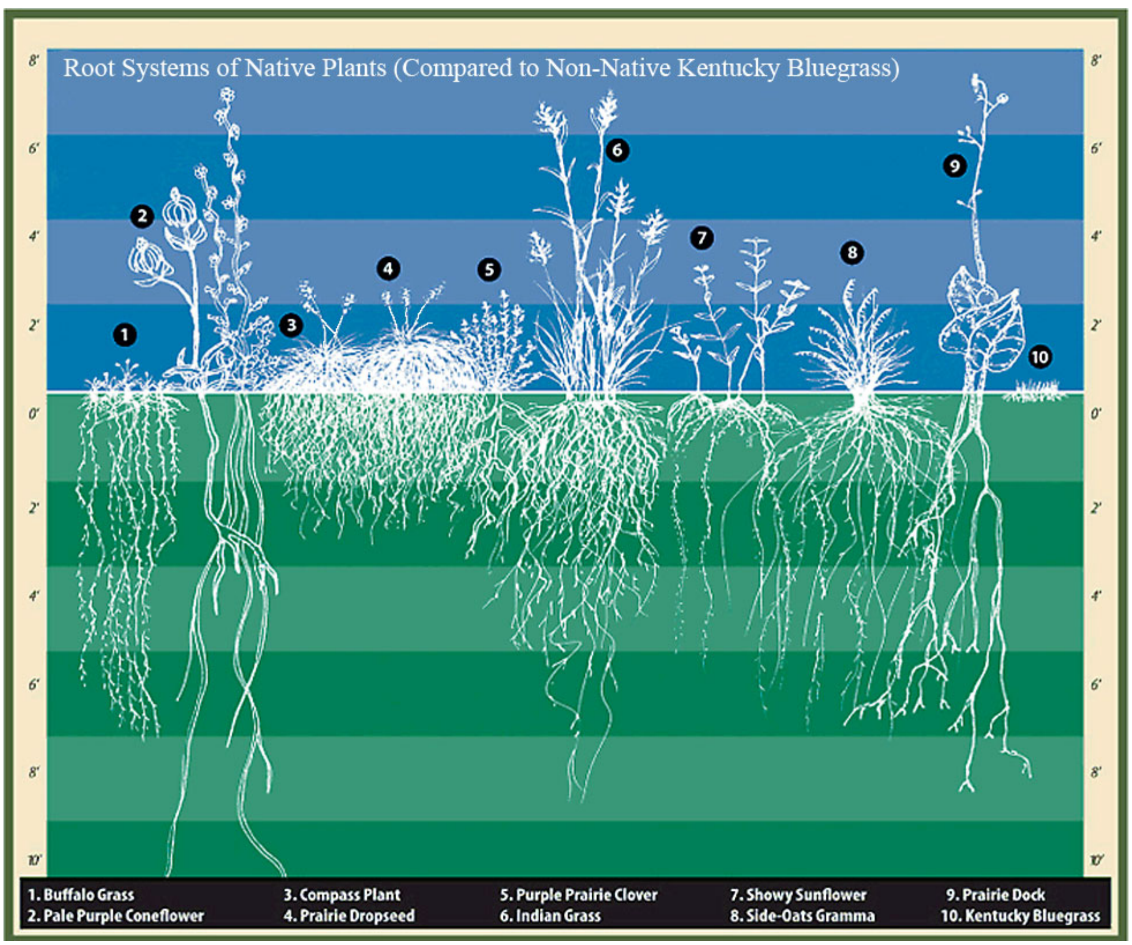


Figure 3-28. Comparison of native prairie and turf grass root and shoot growth.

Turf type and management practices also influence the behavior of turf in terms of changes in runoff hydrology and pollutant loadings. *High-input turf* is irrigated, frequently mowed, fertilized at rates of 3 to 5 lbs N/1,000 ft^2/year, and/or treated with pesticides as part of its regular maintenance regime. *Low-input turf* has little or no irrigation, is frequently mowed, fertilized at lower rates (1-2 lbs N/1,000 ft^2/year), and has low pesticide application. *No-input turf* is not irrigated, fertilized, or treated with pesticides and in some cases is mowed infrequently or not at all (Wilbe 2010).

5.2 Turf-Related Impacts

The following section contains descriptions of the main water quality related effect that can result from the cultivation and maintenance of turf.

5.2.1 Fertilizer Applications

The rate at which fertilizer is applied to home lawns and commercial and institutional landscaping varies depending on the level of maintenance (high or low input) and who is maintaining it (homeowners or lawn care companies), as shown in Table 3-53.

Table 3-53. Lawns managed by homeowners versus other lawn services

Comparative chemical application rates in pounds/acre/year in Maryland					
Chemical	**Cropland[a]**	**Golf fairway**	**Greens**	**Home lawn (do-it-yourself)**	**Home lawn (lawn service)**
N	184	150	213	44–261	194–258
P	80	88	44	15	no data
Pesticides	5.8	37.3	45.1	7.5	no data

Source: http://www.cwp.org/Resource_Library/Center_Docs/PWP/ELC_PWP129.pdf.

Note: a. Corn/soybean rotation

A residential lawn care survey, undertaken by Law et al. (2004) as part of the Baltimore Ecosystem Study, assessed fertilizer application rates and the factors that affect those rates to estimate N input from lawn care practices in urban watersheds. The results indicated a wide range in the rate of fertilizer N applied by homeowners and lawn care companies, averaging 1.99 lb/1000 ft2/year (about 88 pounds per acre) with a standard deviation of 1.81 lb/1000 ft2/year. Factors that affected fertilizer application rate include social economic factors (market value of the house, age of development) and soil characteristics (soil bulk density and soil N content). A 2010 inspection of information provided on lawn fertilizer products sold in gardening and appliance stores in the Chesapeake Bay watershed found that the manufacturers typically recommend four fertilizer applications annually. On the basis of the manufacturers' application recommendations, the typical user could apply the products at approximately 140 pounds per acre.

Schueler (2000d) estimates that home lawns account for 70 percent of total turf area in the Chesapeake Bay watershed, half of which is maintained as high-input turf. The remaining 30 percent of total turf area is public turf, including parks, golf courses, schools, churches, cemeteries, median strips, utility corridors, and office parks, of which one-third is estimated to be maintained as high-input turf. Applying those estimates to the estimated 3.8 million acres of turf in the Chesapeake Bay watershed yields 1.71 million acres maintained as high-input turf and 2.09 million acres maintained as low-input turf. Annual N applied to turf areas in the watershed, estimated using the definitions of high-input and low-input turf presented above, is approximately 389 million pounds of N per year.[1] Such a magnitude of N use in the watershed underscores the need for management practices that reduce risk, ranging from high-quality nutrient management planning and implementation by institutions to turf reduction actions, to prevent excess N from entering the Bay.

5.2.2 Irrigation

Irrigation of turf grass contribute to water shortages and overwatering can lead to poor turf health and runoff problems. Turfgrass-dominated landscapes can require the use of more water than landscapes consisting of a mix of groundcovers, shrubs, and trees. Grass generally consumes eight units of water compared to the same area of trees (five units), and shrubs and ground covers (four units) (Foster 1994).

5.2.3 Energy and Air Quality

Lawns that are mowed have energy costs and air quality impacts, depending on the type of mower used. According to Paul Tukey, founder of SafeLawns.org, a Maine-based nonprofit dedicated to minimizing the environmental effect of lawn care, gas-powered mowing, weed-whacking and edging a modest-sized lawn (625 square feet) for one month would use approximately 6 kilowatt hours or 0.2 gallon of gas (Mosko 2009).

Gas-powered lawn tools are also significant sources of smog and carbon monoxide. According to Clean Air Lawn Care's Clean Lawn Calculator (http://www.cleanairlawncare.com/calculator/), assuming conditions consistent with Maryland or Virginia with 36 mows per year for 1.7 million acres of high-input turf in the Chesapeake Bay watershed, gas-powered lawn equipment

[1] For this calculation, high-input turf is assumed to have an N application rate of 4 lb N/1000 ft^2/year, which is the midpoint of the high-input range defined previously. The N application for low-input turf is assumed to be 1 lb N/1000 ft^2/year, which is the low end of the 1 to 2 lb N/1000ft^2/year range to account for homeowners who do not apply any fertilizer.

produces 3,891,470,584 annual pounds of air pollution. That number can be reduced to 2,233,912,919 by using electric lawn equipment (powered by conventional energy) because electric mowers emit 3,300 times less hydrocarbons, 5,000 times less carbon monoxide, and one-fifth as much smog-forming N oxides as gas lawn mowers. Self-powered push mowers do not generate any air pollution, and they have the added benefit of mulching and depositing grass clippings on the lawn.

5.3 Turf Management Strategies, Practices, Resources and Examples

To ensure that turf performs optimally from a water-quality as well as a broader environmental perspective, the following turfgrass cultural practices should be promoted and encouraged.

5.3.1 Turf Landscape Planning and Design

The design of landscapes should be considered within the context of the site, facility and watershed. The use or degree of use of turf on a site will be dependent on a number of factors such as existing vegetative cover, soils, geology, intended use of the site and other environmental factors such as water quality and wildlife habitat protection. In areas where the natural vegetative cover, e.g., mature deciduous hardwood forest, will be initially developed, the designer should strive to retain as much natural vegetative cover as possible within the design context of the new development to preserve site hydrology, soils and existing wildlife habitat and reduce the need to restore, plant and manage disturbed soils. Lands regardless of vegetative cover type that are obviously degraded should be managed differently and can require restoration. For example, redevelopment and retrofit projects often present the designer with a much different set of factors and challenges to contend with given the existing site conditions. Soils in heavily urbanized areas and brownfields are often very poor, compacted, and not good media for growing and sustaining healthy plants; nor do they promote the level of infiltration necessary to reduce runoff, prevent erosion, filter pollutants maintain stream baseflow and aquifer recharge. Turf, in such conditions, might be a suitable choice for the designer to help restore the hydrologic function of the urban landscape, reduce pollutant loadings resulting from erosion of degraded soils, and provide urban open spaces. Designers also might want to consider laying vegetation using turf or other groundcovers and shrubbery and trees to increase the benefits of vegetation on runoff interception, evapotranspiration and nutrient uptake, and wildlife habitat.

Rating systems or metrics such as the Sustainable Sites Initiative (SSI) Guidelines and Performance Benchmarks 2009 might be useful in assessing designs to determine how well the designs meet multiple objectives for site sustainability in terms of site hydrology, vegetation, soils, human factors, and such. More information on SSI and similar rating systems is at the following sites:

- Sustainable Site Initiative Guidance and Performance Benchmarks 2009 (http://www.sustainablesites.org/report)
- Leadership for Energy and Environmental Design, LEED® for New Construction & Major Renovations (http://www.usgbc.org/ShowFile.aspx?DocumentID=1095)

5.3.2 General Turfgrass Best Cultural Practices

The following list of practices can be used to promote healthy turf that provides the desired use and environmental performance (Wilbe 2010). More details and examples of specific turf management practices are provided in subsequent sections.

Soil improvement

- Mulch clippings back into the grass. Recycling clippings onto lawns improves soil organic content and returns nutrients to the soil.
- Aerate compacted sites annually. Aeration loosens soil to improve water infiltration, air exchange, and plant rooting.
- Apply nutrients, as appropriate according to management goals, in spring, fall, or both, when roots are actively growing. Feeding stimulates root development, which in turn adds more organic matter to improve soil qualities.
- Mulch deciduous tree leaves into lawn areas. Directly mulch leaves into turfgrass where they will degrade into the turf canopy and add soil organic matter.

Preserve or enhance stand density

- Mow at heights of 3 inches and higher. Grass maintained at higher heights will support a larger root system to best sustain itself especially during times of stress. Taller grass can also help to naturally crowd out invasive weeds.
- Use soil and turf enhancement practices to increase turf density as appropriate for use, location, and environmental goals.

Water conservation

- Avoid watering during drought periods. Grass can go dormant in months when water is scarce and safely recover when rains return.

- Mow high to capture more water. Taller grass maintains denser roots to access more available soil moisture throughout the year.
- Feed in the spring and/or fall months. Feeding in the spring allows grass to grow deeper roots and develop reserves prior to summer stress periods. Fall feeding helps grass recover from any damage

Fertilizer care

- Feed only when grass is actively growing. Avoid feeding during periods of drought or when the ground is frozen (December–March).
- Apply fertilizer only to lawn areas. Sweep any material from paved impervious surfaces back onto lawns. Avoid fertilization runoff or deposition into waterbodies.
- Use proper fertilizer spreaders that have been calibrated. Use drop or rotary spreaders with side guards to keep fertilizers off of impervious surfaces
- Avoid fertilization before heavy rainfalls

Clippings management

- Sweep clippings off of impervious surfaces to avoid discharges into surface waters.

The Golf course industry provides a good example that illustrates the benefits of outreach and education efforts that promote the implementation of better practices. The industry—recognizing its role in promoting golf course designs and management practices that can be used to manage turf in an environmentally sound manner—developed golf course design and management principles and research and educational programs to promote that agenda.

The Golf and Environment Initiative was developed to further promote those goals. More information is at http://www.golfandenvironment.com/.

Numerous states and communities are also addressing the need to promote consistency and improved practice in terms of golf course management. The *Golf Course Water Resources Handbook of Best Management Practices*—recently produced by LandStudies, Inc., and the Pennsylvania Environmental Council, funded by the Pennsylvania Department of Environmental Protection (2009)—is one example of such a tool. The handbook pulls from the knowledge and experience of many golf course superintendants and provides a nice background on the importance of mapping, irrigation and water reuse practices, selecting and applying chemicals and fertilizers knowledgably, increasing the use and area of native plants and naturalized areas, as well as other topics. The document reviews 18 BMPs specific to golf courses. The document is at http://www.pecpa.org/files/downloads/Golf_BMP_Handbook_3.pdf.

Public education is also an important aspect of promoting better turf management practices. A good example of a program developed to change public behavior and promote better cultural practices to manage turf is Austin, Texas', *Grow Green* program. The city recognized the need to protect the Edwards aquifer and surface water quality from nutrient impairments and conducted a lawn fertilization and management study to reevaluate common fertilizer recommendations. As a result, the city recommended new residential lawn fertilization practices that change those promoted statewide for the last 20 years. Those recommendations were developed within the context of a comprehensive outreach program that educates the public about proper turf management practices. This program is a partnership among extension offices, retailers, nurseries, and government (state, municipal and federal). More information is at: http://www.ci.austin.tx.us/growgreen/.

5.3.3 Fertilizer Management

Soil tests are commonly used to manage fertilizer applications to optimize application rates and reduce runoff and leaching. Determining the nutrient N and P needs of lawns by the soil concentrations of P might not adequately predict proper application rates or potential for runoff or leaching of nutrients. Furthermore not all soil tests analyze for soil N content.

N should be applied on the basis of established requirements for grass species, season of growth, and intended use. Ideally fertilizers should be applied on the basis of the limiting nutrient and concentrations of nutrients determined by soil testing and local experience and research recommendations for the species being cultivated. Soldat et al. (2008) examined soil P concentrations in New York State and reported that their results suggest that "soil testing will not be an effective tool to predict runoff from turfgrass areas across the range of soil P levels common to New York State." Spreaders used to apply the fertilizer should be carefully calibrated to ensure even application at prescribed rates. The timing and methods of fertilizer application are also important. Lawn fertilizer should be applied in the early or middle spring and in the fall when turfgrass absorbs the most nutrients; fertilizer should never be applied when the ground is frozen (Wilbe 2010). Weather is also a consideration; fertilizer should not be applied during or before wind or rainstorms to prevent pollution of air and surface runoff. The type of spreader used can also reduce pollution; drop spreaders or rotary spreaders with a side guard help to keep fertilizers on the lawn and off impervious surfaces (Wilbe 2010). To determine application recommendations, refer to local guidance.

A number of researchers have demonstrated a connection between proper N fertilization, increased infiltration and reductions in runoff volume and P losses in runoff. (Easton and Petrovic 2004; Kussow 2008). Increasing plant density through fertilization can be a means to reduce runoff velocity and promote infiltration. Soldat and Petrovic (2008), however, also noted that, "Sediment losses from turf areas are negligible, generally limited to establishment, but runoff and leaching losses vary from inconsequential to severe depending on rate, source and timing of fertilizer application," and "Soil properties were found to have a larger effect on runoff volume than vegetative properties." Areas where turf is exists or is planned should be evaluated to determine whether fertilization and soil improvements can improve runoff management performance.

Some communities have implemented policies to restrict fertilizer application or prohibit P-containing fertilizers in watersheds that are sensitive to P enrichment. The following are examples of such types of policies.

- Chesapeake Bay Program Memorandum of Understanding (MOU): On September 22, 2006, the Chesapeake Executive Council, Headwater State Jurisdictions, and members of the lawn care product manufacturing industry signed an MOU that was intended to achieve a 50 percent reduction in the pounds of P in do-it-yourself lawn care products by 2009 (as compared to a 2006 base year). The MOU further committed the signatories to reduce N nutrient losses by recommending possible changes in product content, form, or application method, as well as develop outreach materials to educate the general public on the use of fertilizers. As a result, the industry achieved a 76 percent reduction in P before 2010, with elimination of P from all maintenance products scheduled for 2012; introduction of soil testing for homeowners; adoption of new applicators with a side guard that prevents application to hard surfaces as a standard feature; and education and outreach (radio public service announcements, print media, improved labeling, and point of purchase education). In addition, all lawn fertilizers now contain slow-release N and limited amounts of soluble N. Finally, a 32 percent reduction in N application rates and overall N pounds sold and used has been achieved compared to 2006.

- Annapolis, Maryland, recently became the first municipality in the Chesapeake Bay watershed to adopt an ordinance banning the use of fertilizer that contains P. Since January 1, 2009, residents have been required to use only P-free fertilizer, except in gardens, on newly established turf, and in cases where a soil test shows a P deficiency. For more information, see www.annapolis.gov/upload/images/government/council/Adopted/o1008.pdf.

- The New Jersey Department of Environmental Protection (NJDEP) is mandating that more than 100 New Jersey municipalities adopt local ordinances prohibiting the use of fertilizers containing P except under special circumstances (see ordinance details at www.state.nj.us/dep/watershedmgt/DOCS/TMDL/Fertilizer Application Model Ordinance.pdf). The state is also working to reduce fertilizer application statewide. In April 2008 NJDEP signed an MOU with two major fertilizer producers to reduce the amount of P in their lawn fertilizer products, distribute these products in garden centers statewide, and work with NJDEP to develop strategies to educate the public about proper selection and use of lawn fertilizer. For more information, see *Recent Partnership Limits Phosphorus in New Jersey Fertilizer*, on page 12 of *Nonpoint Source News-Notes* issue 86, at www.epa.gov/NewsNotes/pdf/86issue.pdf (USEPA 2009b). To date, a 50 percent reduction in pounds of P sold in the state has been achieved compared to 2006 levels, and a workgroup has been established to support the Healthy Lawns & Clean Water initiative. The Scotts Miracle-Gro Company received an Honorable Mention in the Governor's Environmental Excellence Awards in 2009 for achieving a 70 percent statewide reduction of P sold in the state and for execution of Healthy Lawns & Clean Water outreach materials.

- Township of Jefferson, New Jersey: Within the township, no person, firm, corporation, or franchise is to apply liquid or granular fertilizer containing P. No lawn fertilizer of any kind is to be applied on frozen ground or within 10 feet of a body of water, including wetlands. http://www.jeffersontownship.net/Cit-e-Access/news/index.cfm?NID=3762&TID=4&jump2=0

- Montville Township, New Jersey: Adopted July 2008, applying fertilizer is prohibited during a runoff-producing rainfall or before a runoff-producing rainfall is predicted to occur. Fertilizer application is also prohibited when soils are saturated and fertilizer can move off-site. Application is further prohibited on impervious surfaces, within 25 feet of a waterbody, and more than 15 days before the start or at any time after the March 15 to October 31 growing season. P-containing fertilizer is strictly prohibited anywhere outdoors at any time except where demonstrated to be necessary for the specific soils and target vegetation, as noted by Rutgers Cooperative Research and Extension's annual fertilizer recommendation. http://www.montvillenj.org/index.php?option=com_content&task=view&id=487

- Suffolk County, New York, Fertilizer Prohibition: A new law prohibits lawn fertilizer applications from November 1 to April 1 to prevent N runoff from frozen ground. The law, which also requires retailers to post signs near fertilizer displays advising customers of the date restrictions, took effect in January 2009. Violators, whether landscapers or homeowners, risk fines of $1,000. Licensed landscapers are required to participate in a 4-hour, county-sponsored session administered by the Cornell Cooperative Extension to renew their licenses. For more information, see http://www.nytimes.com/2009/03/15/nyregion/long-island/15fertilizerli.html?pagewanted=2&_r=1

- Highland Park, Illinois, Phosphorus-Based Fertilizer Ordinance: The Ordinance prohibits the application of fertilizer containing P to any area within city limits unless the user meets one of the three allowable circumstances contained in the ordinance. For example, the fertilizer containing P can be used in areas where the ambient P content is below the median P area for typical soils or the fertilizer is used under a tree canopy.

The ordinance further prevents the retail sale of fertilizer containing P within city limits. For more information, see http://www.cityhpil.com/pdf/Phosphorus-BasedFertilizerOrdinance.DOC

- Wisconsin Phosphorus Ban: In April 2009, Wisconsin Governor Doyle signed the Clean Lakes bill (2009 Wisconsin Act 9). The bill established a statewide law prohibiting the display, sale and use of lawn fertilizer containing P, with certain reasonable exceptions (e.g., when establishing grass or when a soil test shows that P is needed). The law takes effect in April 2010, which gives retailers time to prepare. Although retailers will not be permitted to display turf fertilizer that is labeled as containing P, they may post a sign advising customers that turf fertilizer containing P is available upon request for qualified uses. The prohibition does not apply to the following: the use of manure that is mechanically dried, ground, or pelletized, or to a finished sewage sludge product; the use of fertilizer that contains P to establish grass during the first growing season; the application of fertilizer where soils are deficient in P; and agricultural land. Violators can be required to forfeit not more than $50 for a first violation and not less than $200 nor more than $500 for a second or subsequent violation. For more information, see http://www.legis.state.wi.us/2009/data/AB-3.pdf.

- Dane County Wisconsin: As of January 2005, no person in Dane County could apply lawn fertilizer labeled as containing anything more than 0 percent P. Restrictions on lawn fertilizer application also include applying any type of fertilizer on frozen or impervious surfaces. http://www.danewaters.com/management/phosphorus.aspx

- Minnesota Fertilizer, Soil Amendment, and Plant Amendment Law: Minnesota enacted a statewide law in 2005 prohibiting the use of P lawn fertilizer unless new turf or lawn is being established, a soil test shows a need for P, or P is being applied to a golf course or sod growing area by trained staff. When such situations do not exist, state law requires P-free lawn fertilizer to be used. For more information about the law, see http://www.mda.state.mn.us/protecting/waterprotection/phoslaw.aspx.

- Buffalo, Minnesota: Effective in 2000, lawn fertilizers were not to be applied on frozen ground, specified as being between November 15 and April 15. And at no time can any person, firm, corporation, or franchise apply liquid or granular fertilizer within the city limits that contains phosphates. Fertilizer application is prohibited on impervious surfaces and on surfaces within drainage ditches or waterways or within 10 feet of a water resource. http://www.ci.buffalo.mn.us/Admin/CityCode/1056.htm

- Sanibel City, Florida: With respect to turf and landscape plants, fertilizers cannot contain more than 2 percent P or more than 20 percent N, with 70 percent of the N required to be slow release. Applications are maxed out at one pound of N per 1,000 square feet, for a total of 4 pounds of N per 1,000 square feet in any one year. Fertilizer can be applied up to six times in one year to a single area. Further, no fertilizer is to be applied on impervious surfaces or within 25 feet of a body of water. Retail businesses were required to post notices about the new regulation near the fertilizer to inform customers. http://www.sanibelh2omatters.com/documents/CITY%20APPROVES%20ENVIRONMENTALLY%20FRIENDLY%20REGULATIONS%20FOR%20FERTILIZER%20USE%20ON%20ISLAND.pdf

- Bellingham, Washington, Municipal Code: The city's municipal code contains restrictions pertaining to commercial P-based fertilizer. The municipal code prohibits the application of commercial fertilizer to residential lawns or public properties within the Bellingham city limits area of the Lake Whatcom watershed, either liquid or granular, that is labeled as containing more than 0 percent P or other compounds containing P, such as phosphate, except when applied to newly established turf or lawn areas in the first growing season. In addition, the municipal code prohibits applying fertilizer to frozen ground and impervious surfaces, and imposes requirements for cleanup of fertilizer that is applied, spilled, or deposited on impervious surfaces. Bellingham's Municipal Code is at http://www.cob.org/web/bmcode.nsf/srch/B5D4E84B824F05EB882561D600601973?OpenDocument.

- Whatcom County, Washington: As of April 2005 for Lake Whatcom and June 2007 for Lake Samish, using commercial fertilizers containing P on residential lawns or on public agency properties in the Lake Whatcom watershed is prohibited. Further, no commercial fertilizer of any kind is allowed to be applied on frozen or impervious surfaces. http://www.mrsc.org/mc/whatcom/Whatco16/Whatco1632.html

A few fertilizer restrictions have been in place for long enough to measure results. The following are two studies of the effectiveness of fertilizer ban policies in the Midwest.

- Reduced River Phosphorus Following Implementation of a Lawn Fertilizer Ordinance (Ann Arbor, Michigan): As part of its efforts to comply with a state-imposed P TMDL to reduce 50 percent of P discharges to the Huron River, the city of Ann Arbor enacted an ordinance that went into effect in 2007 to limit P application to lawns. The estimated effect of full compliance was a 22 percent reduction in P entering the river. The study indicates that after the first year of data collection and analysis, statistically significant reductions were documented for total P and, to a lesser degree, for dissolved P for every month from May to September. The research team states, "with a considerable degree of confidence that P concentrations were lower in 2008 at experimental sites compared with the reference period (2003 to 2005) and that the reductions were coincident with a city ordinance restricting use of lawn fertilizers containing phosphorus." However, the study does not conclude that those reductions were caused by enacting the ordinance, but shows that a correlation exists between reductions in P and the ordinance (Lehman et al. 2009). http://www.umich.edu/~hrstudy/Reports/LRM_08-40_web.pdf.

- Effectiveness of Minnesota Phosphorus Lawn Fertilizer Law: The Minnesota Phosphorus Lawn Fertilizer Law directed the Minnesota Commissioner of Agriculture to report in 2007 on the effectiveness of P lawn fertilizer restrictions. The report indicates that various forms of P-free fertilizers were being sold in stores across the state. For example, the state polled 87 stores and found that in 97 percent of those stores, P-free lawn fertilizer was being retailed. In addition, the report found that the law has reduced the amount of fertilizer containing P that was being used. The report showed a reduction of 141 tons of fertilizer used or 48 percent of use between 2003 and 2006. The law has not increased consumer cost for fertilizer and has generally gained consumer support.

  Additionally, since the law's inception, manufacturers have been able to adapt to the law and produce new P-free fertilizer products. Therefore, the change has also expanded the manufacturer's market for P-free lawn fertilizer in other areas concerned with water quality, including the Chesapeake Bay region, Florida, Michigan, Wisconsin, and other states. The report, however, documents only consumer use and manufacturer development and retail and does not look at the effects on water quality or turf management. It recommends further research to expand on those areas. For more information, see the Minnesota Phosphorus Lawn Fertilizer Law: http://www.mda.state.mn.us/protecting/waterprotection/phoslaw.aspx and the Minnesota Effectiveness Report of Phosphorus Lawn Fertilizer Law: http://www.mda.state.mn.us/en/sitecore/content/Global/MDADocs/protecting/waterprotection/07phoslawreport.aspx.

5.3.4 Pesticide Management

Pesticides in urban runoff have been well documented in monitoring studies conducted by the U.S. Geological Survey (USGS 2007). In addition, the Center for Watershed Protection summarized studies in two articles that indicated that urban land uses were sources of pesticides into surface waters (Schueler 2000b, 2000e).

Pesticide use should be managed to reduce applications via spot applications and the use of integrated pest management techniques (IPM). The use of combined fertilizer and pesticide (e.g., *weed and feed*) products should be avoided.

Barth (2000) found the following:

1. **Weed control and tolerance: Establish a realistic tolerance level for weeds and use least toxic control methods to maintain it.** For a low-input lawn, use least toxic

weed control methods such as cultivation, solarization, flaming, mowing, or herbicidal soap. For a lower input lawn, grow strong healthy grass and it will crowd out weeds. For the lowest input lawn, broaden your definition of *lawn* to include weeds that perform desirable functions. [Note: Increasing the mowing height can shade the soil surface and inhibit germination of weed seeds.]

2. **Integrated pest management: Establish a realistic tolerance level for pests and use least toxic control methods to maintain it.** For a low-input lawn, use least toxic control methods such as removing or trapping pests, introducing biological control agents, or apply least toxic chemical controls such as insecticidal soaps. For a lower input lawn, grow strong, healthy grass that can resist attack. For the lowest input lawn, use cultural controls to prevent infestation, protect natural predators, and add beneficial soil microbes.

As of January 1, 2010, products containing a combination of fertilizer and herbicide (commonly known as weed and feed) are no longer available for sale or use in the Canadian province of Alberta. That ban on the use of weed and feed fertilizers is because of potential health and environmental impacts. Because weed and feed is applied to an entire lawn, regardless of the size of the weed infestation, it results in an over-application of the herbicide 2, 4-D. Herbicide-only products will still be available for spot application, because they result in less surplus chemical draining from the lawn, running into storm sewers and entering waterways (Environment Alberta 2010).

5.3.5 Mowing

Lawn mowing practices can affect the amount of fertilizer, pesticide, and irrigation inputs needed. Mowing to a height of at least three inches shades out weeds, slows moisture loss, protects grass vigor, and encourages deeper root growth. When grass is mowed too low, the soil is exposed to light, which can stimulate weed seed germination (Barth 2000).

Mowing frequency is also an important factor. A general rule is to ensure that no more than one-third of the grass leaf be cut at one time to prevent plant damage. Actual mowing frequency will depend on the rate at which the grass is growing, which varies throughout the year (Barth 2000).

Recycling grass clippings by mulching them with a mulching mower and leaving them on the lawn provides nutrients, helps to build soils, and preserves landfill space. Also, mulching leaves into the grass adds organic matter and nutrients (Wilbe 2010). According to surveys, nearly 60 percent of Chesapeake Bay residents practice this form of grass recycling. Using a mulching mower can help meet at least one-fourth of the nutrient needs of a yard and saves time required to bag the clippings (Town of Culpeper 2009). A study by the University of Connecticut Agricultural Station, as reported by Barth (2000), found that most of the N from recycled clippings was incorporated into new grass growth within a week. The Rodale Institute Research Center found that an acre of clippings provides an average of 235 pounds of N and 77 pounds of P each year (Schultz 1989). Austin, Texas, having studied residential lawn fertilization practices, recommends that by leaving clippings on the lawn, 60 percent of the clippings' N and 100 percent of the P will be available to the grass within the growing season (Garrett no date). Grass clippings, leaves, fertilizer, and yard debris should be kept away from impervious areas, because if left in the gutter or streets, they will be washed into storm sewers and surface waters (Wilbe 2010).

5.3.6 Soil Amendments

Background—Soil Compaction

Urban soils have been shown to be more compacted than undisturbed soils (Schueler 2000c), generally as a result of construction activities, heavy equipment use, and intentional compaction. Foot and vehicular traffic can also compact soils. As measured by bulk density (defined as the mass of dry soil divided by its volume, expressed in units of grams per cubic centimeter (gms/cc)), undisturbed soils average 1.1 to 1.4 gms/cc, whereas urban lawns range from 1.5 to 1.9 gms/cc and athletic fields and fill soil typically range from 1.8 to 2.0 gms/cc. The bulk density of these disturbed soils can approach those of concrete (2.2 gms/cc).

An inverse relationship exists between soil bulk density and soil porosity, which indicates that compacted urban soils do not infiltrate stormwater as readily as undisturbed soils. The hydrologic consequence is higher runoff coefficients (Table 3-54), from 0.2 up to 0.5 (paved areas have runoff coefficients ranging from 0.5 to 0.99).

Soil compaction also has implications for plant growth and can restrict root growth, oxygen diffusion, nutrient retention, soil fauna, and inhibit beneficial fungi and other soil biota (Ocean County Soil Conservation District 2001).

A study in North Central Florida revealed that construction activities reduced lawn infiltration rates from 70 percent to 99 percent in comparison to untouched natural forest and pasture. "The compacted pervious area effectively approaches the infiltration behavior of an impervious surface," which increases stormwater runoff and the need for large stormwater conveyance networks (Gregory et al. 2006).

Table 3-54. Runoff Coefficients (C) for Rational Formula

Land use	C	Land Use	C
Business: Downtown areas Neighborhood areas	 0.70–0.95 0.50–0.70	***Lawns:*** Sandy soil, flat, 2% Sandy soil, avg., 2-7% Sandy soil, steep, 7% Heavy soil, flat, 2% Heavy soil, avg., 2-7% Heavy soil, steep, 7%	 0.05–0.10 0.10–0.15 0.15–0.20 0.13–0.17 0.18–0.22 0.25–0.35
Residential: Single-family areas Multi units, detached Munti units, attached Suburban	 0.30–0.50 0.40–0.60 0.60–0.75 0.25–0.40	***Agricultural land:*** *Bare packed soil* *Smooth *Rough *Cultivated rows* *Heavy soil, no crop *Heavy soil, with crop *Sandy soil, no crop *Sandy soil, with crop *Pasture* *Heavy soil *Sandy soil Woodlands	0.30–0.60 0.20–0.50 0.30–0.60 0.20–0.50 0.20–0.40 0.10–0.25 0.15–0.45 0.05–0.25 0.05–0.25
Industrial: Light areas Heavy areas	 0.50–0.80 0.60–0.90	*Streets:* Asphaltic Concrete Brick	 0.70–0.95 0.80–0.95 0.70–0.85
Parks, cemeteries	0.10–0.25	Unimproved areas	0.10–0.30
Playgrounds	0.20–0.35	Drives and walks	0.75–0.85
Railroad yard areas	0.20–0.40	Roofs	0.75–0.95

Source: http://water.me.vccs.edu/courses/CIV246/table2_print.htm
* The designer must use her or his judgment to select the appropriate *C* value within the range. Generally, larger areas with permeable soils, flat slopes, and dense vegetation should have the lowest C values. Smaller areas with dense soils, moderate to steep slopes, and sparse vegetation should have the highest C values.

In examining 15 home lawns in central Pennsylvania, Hamilton and Waddington (1999) find excavation procedures and lawn establishment to be the most influential practices affecting lawn infiltration rates. Homes with minimal soil compaction had the highest infiltration rates. Reduced compaction was achieved by bringing in topsoil post-home construction and through core cultivation (aeration of the soil). The lawn with the highest infiltration rate (10cm/hr) was not excavated during construction, allowing “the macropore system to stay intact, preventing aggregate destruction during usual soil moving and handling, and preventing soil stratification when the soil was put back at the excavated sites.” Other practices that can affect infiltration more than anything else are “the stripping of topsoil, traffic on exposed subsoil, the addition of debris to the soil, and stratification of soil upon replacement.”

Solutions to Reduce Soil Compaction

Soil amendments can be used to enhance soil properties and increase the infiltrative and retentive capacity of soils. Soils can be amended by adding sand or other bulk materials, organic matter such as compost, inorganic or organic fertilizers. Some evidence exists that using compost teas and the inoculation of soils with soil microbes and mycorrhizal fungi can increase soil health and plant productivity. However, most research to date has been conducted on agricultural crops such as maize, wheat, and vegetables. The results of the studies demonstrate that using biological approaches for nutrient management can enhance plant nutrient use efficiency and improve soil water retention, aggregate stability, and the growth of specific crops (Adesomoye et al. 2008; Shaharoona et al. 2008; Ahmad et al. 2008; Dass et al. 2008). Given those results, it is likely that similar benefits will accrue from using biological approaches to turf management. Additional research, however, is needed to determine the benefits that can be achieved by using biological approaches as they relate to the optimization of turf grass performance, nutrient utilization, and soil health.

By mechanically treating, aerating, and amending disturbed soils, the physical structure of the soil can be improved, bulk density can be reduced, and the porosity and infiltrative capacity of the soils enhanced. In fine-textured (clay, clay loam) soils, the addition of compost/organic materials reduces bulk density, improves friability (workability) and porosity, and increases its gas and water permeability, thus reducing erosion. When used in sufficient quantities, adding compost/organic materials provides both immediate and long-term positive effects on soil structure so that fine-textured soils will resist compaction and increase their water-holding capacity. Soil aggregation in coarse-textured (sandy) soils will be improved. Those issues are discussed by Schueler (2000a) in an article that addresses reversal of soil compaction.

McDonald (2004) specifies 2 to 4 inches of compost tilled into the upper 8 to 12 inches of soil, depending on soil type, before planting. Balousek (2003) showed a marked decrease in surface runoff volume (36 to 53 percent) when compacted soils were chisel-plowed and deep-tilled, and when soils were also amended with compost, runoff was reduced by 74 percent to 91 percent. Additionally, compost is good source of N, P, and potassium and contains micronutrients essential for plant growth. Therefore, adding compost can also have a positive effect on fertilizer use and pH adjustment (lime/sulfur addition) and help reduce soil compaction. The benefits of compost are described in more detail in the Composting Council fact sheet, *Using Compost in Stormwater Management*, at www.compostingcouncil.org.

Redmond, Washington, has developed *Guidelines for Landscaping with Compost Amended Soils* (City of Redmond Public Works 1998). The document also contains data on the comparative costs of the use of soil amendments versus the use of other soil preparation methods, and describes the benefits in terms of payback and increased infiltration rates and reduced runoff. The city also quantified the reduced costs for detention facilities accrued from using compost-amended soils because of the increase in moisture-holding capacity of the amended soils. According to Hielema (1996), “the amended plots generated 53 percent to 74 percent of the runoff volume produced by unamended plots under saturated conditions.” Thus, under such conditions, stormwater detention facilities could be reduced in size because of the holding capacity of the amended soils.

McCoy (2006) noted that soil amendments and soil treatments can be used to reduce compaction and increase infiltration. For example, additions of sand and gravel in the design of multiple layer soil profiles can reduce soil compaction and have the potential to decrease runoff and retain water for subsequent evapotranspiration.

For more information, see the manual, *Building Soil: Guidelines and Resources for Implementing Soil Quality and Depth BMP T5.13* in Washington Department of Ecology’s *Stormwater Management Manual for Western Washington 2010 Edition* (http://www.buildingsoil.org/tools/Soil_BMP_Manual.pdf).

5.3.7 Water Management

Landscape irrigation uses up to 1.5 billion gallons of water every day across the country (EPA WaterSense). As reported by Mosko (2009), the Metropolitan Water District of Southern California determined that up to 70 percent of residential water use in Southern California is for outdoor irrigation, particularly lawns. Although the number of lawns in California is unknown, 84 percent of respondents in a 2000 statewide Air Resources Board survey described having a lawn area, and the *San Diego Union* recently reported an estimate that residential lawns cover 300,000 acres and annually soak up 1.5 million acre-feet of water.

According to Mosko (2009), the most popular grasses in Southern California are fescues, which generally require one inch of water per week during dry months and mowing about every other week. Assuming modest-sized lawn areas of 25 feet by 25 feet in both front and in back yards, the lawns could consume, in a single month, in excess of 3,000 gallons of water plus the 34 kilowatt hours of electricity required to deliver the water to Southern California homes.

Among other things, irrigation water waste is a product of inefficient system design, leaks, improper nozzle use, broken nozzles, improper system pressure and improper watering schedules. Excess water use can result in adverse environmental impacts, including over-drafting groundwater resources, reduced stream flows, water quality degradation, and disruptions to the ecosystems that depend on the water supplies (Vickers 2001).

Landscapes with automatic irrigation systems use more water than landscapes that water by hand. In-ground sprinkler systems, automatic timers for irrigation, and drip irrigation systems use 35 percent, 47 percent, and 16 percent more water than residences without these systems, respectively (Mayer and DeOreo 1998). Although, hand-watering or using drought-tolerant vegetation is most efficient, when irrigation systems are desired, reduced water consumption can result from using efficient equipment; proper design, installation, and maintenance of systems; and performing irrigation system audits regularly.

Efficient Irrigation Controllers

Weather-based irrigation controllers can produce water savings when replacing standard clock timer controllers. Weather-based controllers schedule irrigation according to landscape needs and local weather conditions. The technology eliminates the need for manual adjustments to the irrigation schedule. In a Las Vegas, Nevada-based study, researchers found that evapotranspiration-based controllers saved 20 percent more water than non-evapotranspiration-based controllers (Devitt et al. 2008). In a study in Irvine, California, researchers found the use of weather-based evapotranspiration controllers resulted in average water conservation savings of 41 gallons/day. Highest water savings were seen in the summer and fall when irrigation system use is highest. Researchers also found an average runoff reduction of 50 percent for those sites that employed use of weather-based irrigation controllers (IRWD 2004).

EPA's WaterSense program has released a draft specification for weather-based irrigation controllers and will label water-efficient controllers that meet its specification. Weather-based irrigation controllers that earn the label must demonstrate that they meet the watering needs of a typical landscape while not overwatering. For more information on the WaterSense label for irrigation controllers, see http://www.epa.gov/watersense/products/controltech.html.

Efficient Irrigation Practices

To distribute water evenly to an irrigated landscape, an irrigation system must be designed and installed with water efficiency in mind. Poorly designed irrigation systems result in water loss by overwatering certain landscape areas causing runoff while under-watering other areas. Landscape caretakers that use an irrigation system should ensure that the system is operating efficiently by understanding the distribution uniformity (DU) of the irrigation system. DU is a measure of the evenness of water applied to a landscape. An optimally performing irrigation system will have a DU of 80 percent for rotary sprinklers and 75 percent for spray sprinklers (The Irrigation Association 2007).

To test the DU of an irrigation system, a catch-can test is performed. A catch-can test involves several steps: (1) note location of sprinkler heads; (2) place identically sized containers near each sprinkler head and between heads; (3) run the sprinkler system until a minimum of 25 mm of water is collected in a container; (4) record the volume of water collected from each container; and (5) calculate the distribution uniformity:

$$DU = \frac{\text{Average catch-can volume in lower 25\% of catch-cans}}{\text{Average catch-can volume overall}}$$

If the DU of a system is below 50 percent, consider hiring an irrigation professional to adjust the system to obtain better performance and water savings. For more information on distribution uniformity and the catch can test, see http://www.ci.windsor.ca.us/DocumentView.aspx?DID=522.

EPA's WaterSense program partners with irrigation professionals trained in water-efficient design, installation and maintenance, and auditing irrigation systems. An irrigation system auditor will perform a catch can test on a property and provide customers with suggestions for improving irrigation system efficiency. Although, as mentioned, watering by hand is the most efficient means to irrigate a landscape, if an irrigation system is desired, use professionals trained to reduce water consumption. For a list of WaterSense irrigation professionals, see http://www.epa.gov/watersense/meet_our_partners.html.

Deficit irrigation, which is the practice of irrigating below the maximum water demand of the turfgrass to decrease soil moisture content and water use can also be used to reduce water consumption and irrigation. Shearman (2006) reported that water savings of 21 and 40 percent were feasible in a test plot in Nebraska when Kentucky bluegrass received deficit irrigation of 60 and 80 percent of potential evapotranspiration while maintaining an acceptable turfgrass quality.

5.3.8 Grass Species Selection

Some grass species perform better than others under low-input management. In a 5-year field trial in Rhode Island, hard fescue, tall fescue, colonial bentgrass, red fescue, and koeleria (prairie junegrass) were able to maintain 100 percent turf cover on poor soil with no irrigation or pesticides after establishment and only 1 to 2 pounds of N per 1,000 square feet per year applied as organic, granular fertilizer. Kentucky bluegrass and perennial ryegrass were not able to maintain cover under those conditions (Brown, R., personal communication 2010).

Another study in Rhode Island concluded that actively growing turfgrass used an average of 25 mm (1 inch) of water per week in July through September. Average rainfall for the same 12-week period is roughly 300 mm (12 inches). The water-holding ability of good soil and an ability to go dormant if needed allows the grasses survive despite interannual variations in rainfall patterns and timing. In fact, choosing grasses that can survive a dormancy period, and allowing the plants to go dormant during prolonged dry periods is a key strategy for reducing water use (Carrow et al. 2008).

According to Beard and Green (1994), "the proper strategy based on good science is the use of appropriate low-water-use turfgrasses, trees, and shrubs for moderate-to-low irrigated landscapes and similarly to select appropriate dehydration-avoidant and drought-resistant turfgrasses, trees, and shrubs for nonirrigated landscape areas." It is also important when choosing grasses for low-input management to use improved varieties. The improved varieties have denser growth and better disease resistance than *common* types (Brown, R., personal communication, 2010).

Devitt and Morris (2006) note the need to consider the effects of landscape species selection including turf on water conservation and use, i.e., "Plant selection should be given serious consideration in the development of low water-using landscapes." The authors also recommend that,

> [E]mphasis should be placed on the following factors:
>
> 1. Price water on the basis of its true societal value as a scarce resource.
> 2. Decrease irrigated landscape areas.
> 3. Track irrigations and adjust for changes in the seasonal demand of water. Irrigating based on seasonal demand will almost always use less water than irrigating based on guesswork.
> 4. Adjust landscape expectations down whenever possible and be more flexible in plant selection (especially with those plants know to be high water users). Low growth rates by decreasing fertilization and irrigations to achieve judicious size control.

If turfgrass is planted as ornamental vegetation in a landscape, choose native, drought-tolerant, or low-water-use turfgrass species that require less water and maintenance. To identify species appropriate for a site, consult lists of native species of vegetation. The Lady Bird Johnson Wildflower Center provides native plant lists for the United States: http://www.wildflower.org/. Local cooperative extension units can also provide information on planting regionally appropriate species.

For functional turf areas, traditional turf species might be desired. Traditional turfgrass is distinguished as warm-season or cool-season turfgrasses. Warm-season turfgrasses, such as Bermuda grasses, zoysia grasses, buffalo grass, little bluestem, and Pennsylvania sedge, are usually more drought tolerant and should be used in warmer climates. Some cool-season turfgrasses, such as fine fescues, are drought tolerant but are more appropriate for cold-weather climates. Other cool-season turfgrasses, such as Kentucky bluegrass, require high amounts of water (35 inches per year just for survival) and are inappropriate for many areas in the country (Vickers 2001).

One option when selecting grass species is to increase diversity by creating a mixed species lawn that incorporates clovers or legumes into the turf mixture. A uniform distribution of such plants can be achieved by evenly blending it with grass seed. Benefits include increased drought tolerance, lower N needs, increased pest resistance, and decreased weed infestations (Bellows 2010).

A combination of native grasses can provide a highly resistant, low-maintenance yard or turf. For example, a combination of little bluestem (*Schizachyrium scoparium*), common or Pennsylvania sedge (*Carex pensylvanica*), and tufted hairgrass (*Deschampsia flexuosa*) is well adapted to the Northeastern coastal areas (Bellows 2010).

No-mow lawn mixes are composed of slow-growing turf grasses like hard fescue and creeping red fescues, which require little maintenance because they have deep roots and are resistant to drought. Sedges and rushes can also be used as a low-maintenance ground cover suitable for moist climates (Bellows 2010).

Resources

The National Turfgrass Evaluation Program develops and coordinates uniform evaluation trials of turfgrass varieties and promising selections in the United States and Canada. The results can be used to determine the broad picture of the adaptation of a cultivar. Results can also be used to determine if a cultivar is well adapted to a local area or level of turf maintenance. http://www.ntep.org/contents2.shtml

The National Sustainable Agriculture Information Service (referred to as ATTRA) offers a *Sustainable Turf Care Guide* for lawn care professionals, golf course superintendents, or anyone with a lawn. The emphasis of the guide is on soil management and cultural practices that enhance turf growth and reduce pests and diseases by reducing turf stress. It also includes information about mixed species and wildflower lawns as low maintenance alternatives to pure grass lawns. http://attra.ncat.org/attra-pub/turfcare.html

5.3.9 Turf Assessments

Municipalities and facility owners should have a qualified landscape professional (e.g., a landscape architect, landscape designer, or other trained landscape professional) conduct an assessment of turf areas to identify essential versus nonessential turf and opportunities to reduce turf and decrease the inputs for turf areas that are retained as long as desired turf performance can be achieved.

In some cases, active management of landscapes through irrigation, mowing prescription and fertilization can enhance the environmental performance of the landscape. Easton and Petrovic (2008) evaluated P loading from an urban watershed in New York, measuring dissolved P, particulate P, and TP as well as site characteristic for three land uses: fertilized lawns, urban barren areas, and wooded areas. They found that applying P in excess of plant requirements can result in higher dissolved P in runoff, especially in areas that have been repeatedly over-fertilized, i.e., on lawns. However, particulate (sediment-bound) P was highest in runoff from land uses with the sparsest vegetation cover that have not been actively maintained (urban barren areas and wooded areas). The researchers suggested that these areas could benefit from judicious fertilization to improve groundcover and reduce erosion. Losses of dissolved P from these areas during wet weather can be minimized by properly timing fertilizer applications and matching the application rate to plant needs on the basis of soil tests.

Areas of essential turf should be determined by land owners/operators on the basis of factors they identify. For example, essential turf areas can include turf for transit paths, security, transportation visibility, historic preservation or dedicated recreational purposes such as picnic areas and ball fields, buffers for public health reasons, and water pollution control practices such as grassed swales. Nonessential turf areas are typically grassed areas that have not been planted for a specific use or environmental purpose and receive little or no use or maintenance except periodic mowing. Many of these grassed areas can be maintained only with turf cover because of ease of maintenance, habit or for aesthetic continuity and can be converted to less input-intensive ground covers that can provide increased habitat, improved aesthtics, and/or environmental performance.

All turf areas should be assessed by category and managed accordingly to maximize performance in terms of runoff reductions, erosion, nutrient discharges and infiltration. Areas with thin grass cover, bare soil, or other indications that the turf is not performing optimally from an environmental perspective should be identified and differentially managed by area or category to achieve the desired filtration, water retention, pollutant removal and infiltration objectives. In some cases, landscape managers might elect to convert turf to other landscape cover types, let the turf revert to native forest, or increase management prescription to optimize turf growth, thatch density, and nutrient and sediment retention

To reduce both the environmental effects of turf and management costs, communities and land managers across the country are identifying areas that are mow zones, low-mow zones and no-mow zones in an effort to reduce maintenance and provide increased ecological value from landscaped areas. Converting turf areas back to naturalized areas is also a strategy to eliminate the need to irrigate, fertilize, and apply pesticides except in cases where disease or invasive species are problematic.

For areas that will remain as turf, further evaluation can identify areas that will be actively managed (high-input) versus those that will be mowed and not treated with fertilizers and pesticides. Facilities, campuses and other managers of large tracts of land should develop landscape management plans, maps and operation and maintenance plans to properly manage each designated category of vegetative cover including high-input and low-input turf areas. Facility managers also might want to limit the creation or retention of high-input areas to the most visible and used landscaped areas (e.g., areas adjacent to building entrances, transit paths or areas where high quality turf is deemed essential). In contrast, lawns along the side and back of buildings or at the edges of parking lots might not require such intensive management and can be designated as low-input and low-mow areas. Examples of turf conversion or reduction strategies are provided below.

- The U.S. National Arboretum in Washington, D.C., has undertaken measures to reduce high-maintenance turf areas (U.S. Department of Agriculture, Agricultural Research Service, no date). The Arboretum occupies 446 acres of green space, about half of which is taken up by intensely managed gardens, collections, and research plots. Arboretum managers have drastically reduced the area devoted to turf and have changed the way the turf is managed. Large open spaces that were formerly devoted to turf are now managed as meadows and account for about 70 acres, and areas that are frequently mowed have been reduced to just 31 acres. Instead of mowing turf areas weekly, as is standard practice, they mow in response to height thresholds, so that the turf is mowed only 13 times on average during the growing season instead of 30 times (less if drought slows turf growth). The mowing height threshold is 5 inches, which is much higher than is commonly used on corporate campuses or on residential turf. They do not generally irrigate or fertilizer turf, do not use pesticides or herbicides, and leave clippings on the turf areas.

- Since 1995 the University of Nevada, Las Vegas has reduced turf on campus by 1,056,126 square feet, with an estimated water savings of more than 9 million gallons and more than $20,000 annually. Its efforts include computer-controlled watering of campus turf in compliance with water authority guidelines, enabling automatic shutdown with the use of flow sensors, decoders, and automatic irrigation adjustment through an evapotranspiration database, which is linked to the university's weather station for automatic irrigation adjustment because of changes in weather. All landscaping around new buildings is now xeriscaped, and more than 50,000 square feet of turf has been replaced with desert landscaping at the Shadow Lane Campus. A landscape design is in progress to reduce the heat-island effect of parking lots through tree planting in a project being planned in partnership with the U.S. Division of Forestry. More information is at http://barrickmuseum.unlv.edu/xeric/turf.html.

- Henderson, Nevada, Parks and Recreation Department has a turf reduction program that involves removing nonfunctional turf from targeted areas in the parks system and replacing it with more efficient xeriscaped areas. Since 2003 more than 85 turf conversion projects have been completed, removing more than 1.2 million square feet of turf, mostly from medians, parking lots, and areas where turf is primarily decorative. The turf removal has translated into an annual savings of more than 68 million gallons of water. The program was funded through a variety of grants and rebates rather than tax dollars. More information is at http://www.cityofhenderson.com/parks/parks/turf-conversion.php.

- A study was undertaken at the University of Waterloo in Ontario, Canada, to develop a methodology for assessing all campus areas to identify candidates for turf conversion (Hassan 2000). The study included an evaluation of stakeholder preferences, including turf users (students and faculty) and university staff who maintain turf areas. A set of criteria were established for evaluating existing turf areas according to current conditions, visibility and aesthetics, and feasibility and suitability for alternate plantings. More information is at http://www.adm.uwaterloo.ca/infowast/watgreen/projects/library/grass.pdf.

Another aspect that should be considered in turf management is irrigation. Areas planted in turf should be assessed to determine necessary irrigation regimes and periodically evaluated to identify opportunities to reduce water use on the basis of turf condition and other factors.

Carrow et al. (2008) provided an outline of the planning process and components of golf course BMPs for water use efficiency/conservation that includes a framework for managing golf courses and other landscapes to reduce water use. This assessment process, described below in modified form, could be used to plan, assess and implement programs to promote water use efficiency and conservation at most large, landscaped facilities or jurisdictions (adapted from Carrow et al. 2008):

A. Initial planning and site assessment
   1. Identification of water conservation measures and costs
   2. Purpose and scope of the site assessment
   3. Site assessment and information collection
      a. Current water use profile
      b. Irrigation/water system distribution audit

c. Site assessment information, e.g., alternative water sources, golf course design modifications, and soil and climate conditions

B. Identify, evaluate and select *water conservation strategies*: and options and use the following 10 Core Water Conservation Strategies:

1. Use nonpotable water sources for irrigation—alternative water sources; water harvesting/reuse
2. Efficient irrigation system design and monitoring devices for implementing water conservation, e.g., remote sensing and real-time control devices
3. Efficient irrigation system scheduling/operation
4. Developing and selecting turfgrasses and other landscape plants with respect to water uptake and use requirements in terms of quantity and quality
5. Landscape design for water conservation
6. Altering practices to enhance water-use efficiency, e.g., soil amendments, cultivation, mowing, fertilization
7. Indoor water conservation measures in buildings, air conditioning units, pools, and other facilities associated with a landscape site
8. Educating management and staff in water conservation management practices and approaches
9. Developing formal conservation and contingency plans
10. Monitor and revise plans

C. Assess benefits and costs of water conservation measures on stakeholders

1. Benefits—direct and indirect
2. Costs
   a. Facility costs for past and planned implementation of water conservation strategies and practices
   b. Labor needs/costs
   c. Costs associated with changes in management practice, e.g., water and soil treatments, posting of signs, training

Resource

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5.3.10 Turf Restrictions

Limiting the amount of landscaped area for turfgrass and high water use plantings can reduce landscape irrigation demand. A number of municipalities limit turf areas. For example, the Marin Municipal Water District in California limits use of turfgrass and high water use plants to 35 percent of the total landscaped area (Marin Municipal Water District Ordinance 326, In Vickers 2001). Clark County, Nevada, set limits on turf areas for new properties according to drought conditions. Under non-drought conditions, the following limits apply:

- Single-family homes: 50 percent of a front yard can be grass, not including driveway or parking areas
- Multifamily (apartments, condos) and nonresidential developments: 30 percent of an area set aside for landscaping can be grass, excluding parking lots and driveways
- Golf courses: Limited to a maximum of 90 acres for 18 holes and 10 acres for driving ranges

For nonresidential landscapes, installing new turf is prohibited during drought conditions, with some exceptions for public spaces that have functional turf. For single-family and multifamily developments, installing new turf is prohibited in common areas of residential neighborhoods during a Drought Watch, and during a more severe Drought Alert, new turf is prohibited in residential front yards and cannot exceed 50 percent of the gross area of the side or rear yard or 100 square feet, whichever is greater. A maximum of 5,000 square feet of turf is permitted. The details of the Clark County Drought Restrictions are at http://library.municode.com/HTML/16214/level2/T30_30.64.html#T30_30.64_30.64.010.

5.3.11 Incentives for Landscape Conversion

Some communities use incentives to urge property owners to convert their lawns to less maintenance-intensive landscaping. Federal facilities planners will find such types of municipal incentive programs to be of interest because they provide documentation of the benefits achieved from lawn conversion. The following are examples of lawn conversion incentive programs:

- Cary, North Carolina, initiated a one-time, $500 per property payment to homeowners who convert at least 1,000 square feet of historically irrigated turf to natural area or warm-season grass. Homeowners must demonstrate past irrigation, submit a description of their conversion project, and provide receipts documenting the project. Customers are allowed a waiver of alternate-day watering restrictions to encourage establishment of new plantings, and thereafter are required to reduce their water budgets by 25 percent. A post-conversion site review is conducted to confirm successful establishment of the replacement landscape. During spring and summer months, the town anticipates a savings of about 675 gallons per month for each 1,000 square feet converted to natural landscape, and approximately 567 gallons saved per month for each 1,000 square feet of warm season grass conversion (Town of Cary 2009). http://www.townofcary.org/Departments/Public_Works_and_Utilities/Conservation/Water_Conservation/Incentive_Programs/Turf_Buy_Back_Program/Turf_Buy_Back_Program_Fact_Sheet.htm

- The Southern Nevada Water Authority's (SNWA's) Water Smart Landscapes rebate helps property owners convert water-thirsty grass to xeriscape. SNWA will rebate customers $1.50 per square foot of grass removed and replaced with desert landscaping up to the first 5,000 square feet converted per property, per year. Beyond the first 5,000 feet, SNWA will provide a rebate of $1 per square foot. The maximum award for any property in a fiscal year is $300,000. http://www.snwa.com/html/cons_wsl.html

Resources

EPA's WaterSense program has a specification for water-efficient, single-family new homes that includes landscape criteria. The specification requires use of a water budget tool to help calculate a regionally appropriate allotment of turfgrass for a residence or a turfgrass reduction to 40 percent of the landscaped area. Although the tool is designed for use by builders designing new homes, consumers can use it in existing landscapes to help understand whether their use of turfgrass and other high water using plants is appropriate for their region. To learn more about the water budget tool, see http://www.epa.gov/watersense/nhspecs/homes_final.html

The SSI provides guidance on sustainable landscaping. One of the criteria for which it has developed guidance is site design for water conservation. To participate in the program, landscapes are required to reduce potable water use for irrigation by 50 percent from a baseline. Reductions can be accomplished through using regionally appropriate plantings, irrigation efficiency (drip irrigation), using captured rainwater, and using recycled graywater to name a few. To track landscape water savings, SSI uses a water budget tool adapted from EPA's WaterSense program that has additional criteria, requiring a greater reduction in outdoor water use. For more information, see http://www.sustainablesites.org/.

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5.3.12 Environmentally Friendly Landscape Requirements

Plant selection and planning have a significant effect on the amount of maintenance and inputs needed to maintain attractive landscaping. Landscaping that is considered environmentally friendly requires few inputs and focuses on the use of native landscaping, the use of drought-tolerant or locally adapted plants, and other features such as rainwater harvesting, infiltration areas, and street trees. Several regional programs promote such landscaping principles, including the BayScapes program for the Chesapeake Bay region and Bay-Friendly Landscaping in the San Francisco Bay area. The following are examples of communities that have adopted environmentally friendly landscaping requirements for certain types of development projects:

- The Oro Loma Sanitary District in the San Francisco Bay area of California has adopted an ordinance requiring the integration of green building and Bay-Friendly landscaping strategies in district and public-private partnerships buildings and landscapes. Projects are required to meet the most recent minimum *Bay-Friendly Landscape Guidelines* and Bay-Friendly Landscape Scorecard points (http://www.stopwaste.org/docs/bay-friendly_landscape_guidelines_-_all_chapters.pdf). www.oroloma.org/asset/regulation/ordinance%2043.pdf

- Miami-Dade County, Florida, has established landscaping requirements for right-of-way landscapes that promote xeriscape and *Florida-Friendly* principles by setting minimum standards for irrigation and selection of plant material and mulch. The ordinance requires the use of drought-tolerant species and grouping of plants by water requirements, and it sets limits on irrigation systems. It also aims to promote trees for a variety of environmental benefits and to reduce exotic pest plants. http://www.miamidade.gov/govaction/matter.asp?matter=091097&file=true&yearFolder=Y2009

Resources

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5.3.13 Xeriscaping Requirements

Xeriscaping is a type of landscaping that conserves water through planting of native, water-efficient plants rather than water-intensive ones and using techniques that minimize the need for irrigation. Xeriscaping has water quality benefits in addition to water conservation benefits because it helps to prevent dry-weather runoff from over-irrigation.

Altbough xeriscaping is a common practice in arid areas, the concept can be applied in the Chesapeake Bay watershed. The National Institutes of Health in Bethesda, Maryland, has created ground level xeriscaped areas using green roof soil media and plants near their security entrance to reduce runoff and provide a low maintenance aesthetically pleasing landscape (Figure 3-29).

Figure 3-29. Xeriscape landscaping at NIH Campus (from Waring 2007).

Xeriscaping programs, typically, are voluntary and focus on education and outreach, although some communities have implemented xeriscaping requirements as part of their landscaping codes, and others have developed incentive programs. The following are examples of both regulatory and incentive approaches to xeriscaping.

- Rancho Cucamonga, California, has a xeriscape requirement for developments requiring landscaping plans (with some exemptions, including single-family homes and public spaces). Developments with model homes are required to use xeriscaping on half of the models, including low water use plants, water-saving irrigation systems, and signage indicating to buyers the water-saving landscape design features. http://search.municode.com/html/16570/level2/T19_C19.16.html

- Mesa, Arizona, offers a Grass-to-Xeriscape rebate to encourage single-family homeowners to replace their lawns with xeriscapes. When a customer removes 500 square feet or more of established grass and replaces it with a xeriscape, the Mesa provides a $500 rebate. http://www.mesaaz.gov/conservation/grass-to-xeriscape-rebate.aspx

- Gallup, New Mexico, has a Xeriscape Rebate Application Program in which customers are eligible to receive a rebate on their water bill for each square foot of irrigated turf grass, removed and replaced with an approved xeriscape landscape (the city provides a Xeriscape Plant List). Twenty-five percent of the qualifying total square footage of irrigated turf grass removed must be replaced with qualifying xeriscape plants, subject to inspection and approval. http://www.ci.gallup.nm.us/GJU/Gallup-Xeriscape%20Rebate%20Application.pdf

- In 2006 California passed the Water Conservation in Landscaping Act to require local municipalities to adopt landscape water conservation ordinances by 2010. To assist municipalities with compliance, the state issued a Model Water Efficient Landscape Ordinance and accompanying technical resources, including a compendium of existing local ordinances addressing water-efficient landscaping. The model ordinance and technical assistance information are at http://www.water.ca.gov/wateruseefficiency/landscapeordinance/.

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Appendix 1: BMP Fact Sheets

1.1 Introduction

The BMPs included in this document are not an exhaustive list but represent some examples of low-impact development (LID) practices that have been widely adopted and have proven to be effective in managing stormwater, and where there is new information on existing practices, such as street sweeping. The fact sheets contain technical information and references and are written to be applicable to federal facilities and nonfederal facilities.

Practices such as stormwater detention and hydrodynamic settling devices have an important role in stormwater management and are effectively described in many existing sources (for references, see Section 6). The practices presented in this appendix were selected because they represent newer approaches to stormwater management (such as green roofs or bioretention) or new technologies (such as blue roofs and cisterns) or where new information exists on existing technologies (such as bioretention).

The following BMP fact sheets were prepared for this document because new information is available that is relevant to application in the Chesapeake Bay watershed and potentially elsewhere. Each fact sheet includes a description of the practice, targeted pollutants, photos/diagrams, constraints/limitations, effectiveness, design, maintenance, and costs. Equally important practices that are already well-described on EPA's Web site are not repeated here; instead, links to them are provided below.

Practices with fact sheets in Appendix 1 consist of the following:

1.2 Rainwater harvesting

1.3 Green roofs

1.4 Blue roofs

1.5 Bioretention

1.6 Infiltration

1.7 Soil restoration

1.8 Reforestation/urban forestry

1.9 Street sweeping

1.10 Constructed wetlands

Practices with fact sheets on EPA's Web site consist of the following:

- Downspout disconnection
- Planter boxes
- Rain gardens
- Permeable pavements
- Vegetated swales
- Brownfield redevelopment
- Infill and redevelopment
- Green parking
- Pocket wetlands
- Compost Blanket

EPA's Green Infrastructure Web site:
http://cfpub.epa.gov/npdes/greeninfrastructure/technology.cfm

EPA's Menu of BMPs Web site:
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5

1.1.1 Performance Estimate Summaries for Infiltration Practices

The performance of LID practices varies significantly by the design and the regional climate. In the Chesapeake Bay region, a large infiltration BMP relative to the drainage area could provide infiltration of the 95th percentile storm event or more. The slower infiltration rates of clay type soils results in the need for more storage, but they also have an ability to infiltrate. For additional discussion, see the bioretention fact sheet.

The performance of several of these infiltration practices was recently reviewed for the Chesapeake Bay region to estimate the capability for volume control and pollutant reduction based on the design criteria used in the region (which was not developed to manage the 95th percentile storm event). The Mid-Atlantic Water Program housed at the University of Maryland led a project during 2006–2009 to review and refine definition and effectiveness estimates for BMPs in the Chesapeake Bay watershed. It is called *Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus, and Sediment in the Chesapeake Bay*, (BMP Effectiveness Report) and is at www.chesapeakebay.net/marylandBMP.aspx (Simpson and Weammert 2009). The urban stormwater BMPs reviewed by the Mid-Atlantic Water Program are at http://archive.chesapeakebay.net/pubs/BMP_ASSESSMENT_REPORT.pdf. The LID BMPs reviewed and their definition as reported in the BMP assessment are as follows:

Bioretention: An excavated pit backfilled with engineered media, topsoil, mulch, and vegetation. These are planting areas installed in shallow basins in which the stormwater is temporarily ponded and then treated by filtering through the bed components, and through biological and biochemical reactions within the soil matrix and around the root zones of the plants.

Permeable Pavement and Pavers: Pavement or pavers that reduce runoff volume and treat water quality through both infiltration and filtration mechanisms. Water filters through open voids in the pavement surface to a washed gravel subsurface storage reservoir, where it is then slowly infiltrated into the underlying soils or exists via an underdrain.

Infiltration Trenches and Basins: A depression to form an infiltration basin where sediment is trapped and water infiltrates the soil. No underdrains are associated with infiltration basins and trenches because, by definition, these systems provide complete infiltration.

Filters: Filters capture and treat runoff by filtering through a sand or organic media.

Vegetated Open Channels: Open channels are practices that convey stormwater runoff and provide treatment as the water is conveyed, includes bioswales. Runoff passes through either vegetation in the channel, subsoil matrix, and/or is infiltrated into the underlying soils.

The effectiveness summary from the BMP Assessment Report is provided in Table 3A1-1. The BMP Assessment Report provides a summary of assumptions, data sources, maintenance consideration, and other factors related to these LID practices in the Chesapeake Bay area. Among the assumptions used in preparation of the effectiveness estimates were

- That the estimates reflect performance that might actually be expected where persons less-specialized in bioretention prepare the design and install and operate the BMP, according the design criteria used in the region. This estimates *average* performance. This was intentionally not based on data from controlled research studies on practices designed, built, and maintained by bioretention experts. This does not reflect performance of systems designed to achieve retention of the 95th percentile storm event.
- That the BMPs were designed for a 1-inch storm; at approximately 1 inch to 1.5 inches, the system would begin to overflow. (1.5 inches of rainfall is approximately the 95th percentile rain event in the Chesapeake Bay area.)
- Lined bioretention cells were reported to have poorer performance; the presence of the liner reduces performance to approximately that of C/D soils with an underdrain.

In reviewing the effectiveness values in the table, it is important to note the variability in the estimates, that the estimates are intended to be conservative, and that the majority of the pollutant removal is associated with the volume reduction that occurs from either infiltration or evapotranspiration. For additional information on performance estimates, refer to the Bioretention/Biofiltration fact sheet.

Table 3A1-1. Effectiveness summary from the BMP assessment report

	EMC-based removal (PR)			Runoff reduction (RR)	Mass-based removal (TR) expressed as removal from collection areas (acres)		
	TP	TN*	TSS		TP	TN	TSS
Bioretention							
C/D soils, underdrain	37	10	50	**15**	45	25	55
A/B soils, underdrain	37	10	50	**65**	75	70	80
A/B soils, no underdrain	37	10	50	**80**	85	80	90
					± 20	± 15	± 15
Filter							
All (sand, organic, peat)	60	40	80	**0**	60	40	80
					± 10	± 15	± 10
Vegetated Open Channels							
C/D soils, no underdrain	10	10	50	**0**	10	10	50
A/B soil, no underdrain	10	10	50	**40**	45	45	70
					± 20	± 20	± 30
Bioswale	37	10	50	**65**	75	70	80
					± 20	± 15	± 15
Permeable Pavement (no sand/veg)							
C/D soils, underdrain	10	0	50	**10**	20	10	55
A/B soils, underdrain	10	0	50	**45**	50	45	70
A/B soils, no underdrain	10	0	50	**75**	80	75	85
					± 20	± 15	± 15
Permeable Pavement (with sand, veg)							
C/D soils, underdrain	10	10	50	**10**	20	20	55
A/B soils, underdrain	10	10	50	**45**	50	50	70
A/B soils, no underdrain	10	10	50	**75**	80	80	85
					± 20	± 15	± 15
Infiltration Practices (no sand/veg)							
A/B soils, no underdrain	25	0	95	**80**	85	80	95
					± 15	± 15	± 10

Table 3A1-1. Effectiveness summary from the BMP assessment report *(continued)*

	EMC-based removal (PR)			Runoff reduction (RR)	Mass-based removal (TR) expressed as removal from collection areas (acres)		
	TP	**TN***	**TSS**		**TP**	**TN***	**TSS**
Infiltration Practices (with sand/veg)							
A/B soils, no underdrain	25	15	95	**80**	85	85	95
					± 10	± 15	± 10

Source: Simpson and Weammert. 2009. *Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus, and Sediment in the Chesapeake Bay*. Final Report.

Notes:

1. Soil classification (A, B, C, D) per U.S. Department of Agriculture (USDA) National Resource Conservation Service (NRCS)
2. EMC-based removal expressed as Percent Reduction (PR)
3. Mass-based removal expressed as percent removal of total load by mass (TR)
4. Nitrogen concentration reduction is low potentially because the solubility of nitrate, the potential for organic nitrogen and ammonia to mineralize in the bioretention media to the nitrate form, and the lack of conditions needed for denitrification contribute to nitrogen export.
5. Assumptions include (1) highly impervious urbanized land use; (2) generalized for design criteria typical of bay area jurisdictions; (3) designed, installed and maintained by persons who are not experts in bioretention; 3) low phosphorus soil media; (4) for systems designed for a 1-inch storm, rain events from 1 to 1.5-inch depth will begin to show overflow
6. Total removal estimated by the calculation TR = RR + {(100-RR) × PR)}, rounded to a factor of 5.
7. Authors caution that the estimates, based on limited data and generalized for simplicity, might not represent true long-term performance throughout the watershed. Performance is highly variable even under controlled conditions.

1.2 Rainwater Harvesting

Description of Practice

Rainwater harvesting can play an important role in managing stormwater runoff and can reduce both the costs and energy needed to convey and treat runoff offsite. Rain barrels and cisterns can be used to reduce runoff volume and mitigate peak runoff flow rates for small and medium storm events. Rainwater collected in harvesting systems is typically used only for nonpotable applications, such as irrigation, toilet flushing, and vehicle washing, but uses could expand as demand for water increases. In addition to reducing stormwater runoff, rainwater harvesting has the secondary benefit of reducing potable water demand because nonpotable uses represent up to 40 percent of overall household water demand. Rooftop runoff, because it typically contains low pollutant loads and is easily collected, is the source of most water collected in rainwater harvesting systems.

Harvested rainwater can be routed and stored in two main types of vessels called cisterns or rain barrels. Cisterns generally have a much larger capacity than rain barrels. Cisterns can be designed to hold hundreds or thousands of gallons. Rain barrels most often hold between 55–250 gallons with 55- to 75-gallon barrels being the most commonly used sizes. To capture the rainwater, roof downspouts are piped to the rain barrel or cistern. Most residential rain barrels are installed outside as are many cisterns. However, cisterns can be installed inside residential and nonresidential buildings, outside and above or below grade. Bypass drains or systems are used to divert excess volume when the rain barrel or cistern is full.

Some systems require the use of filtration or disinfection systems depending on the intended use and the size of the system. Rain barrels typically do not require such systems. Filtration and disinfection systems are used to reduce fouling, clogging, bacterial growth, slime formation and to treat the rainwater for its intended uses.

In most areas of the country, the use of rain barrels and cisterns is for water supply. They are also encouraged mainly to reduce the volume of runoff discharged from impervious surfaces, such as to help mitigate localized flooding or combined sewer overflows. In arid or semi-arid areas or areas of period drought rainwater harvesting systems can play an important role in the provision of supplemental irrigation or wash waters. Around the globe, rainwater collection systems are often used to provide potable water. In the United States the use of harvested rainwater for potable uses is restricted because of public health concerns.

Rainwater harvesting systems are most effectively used to reduce runoff volume when they are integrated into a treatment train or system of practices that can include green roofs, permeable pavements, or rain gardens/bioretention cells.

To optimize system performance, the system should be managed either manually or automatically to discharge the captured volume before the next significant storm event occurs. Such management strategies help to ensure that the maximum cistern/rain barrel capacity is available when a rain event occurs. For example, soaker hoses can be used with rain barrels to slowly drain the rain barrel in periods of non-irrigation use and automatic real-time control systems can be used for large nonresidential systems to control the timing of and the release rate of water from the cistern to ensure capacity is available to capture the next storm.

Hydrologic Performance and Targeted Pollutants

Hydrologic Performance

Volume Reduction	Peak Flow Reduction	Groundwater Recharge
⦿[1]	⦿[a]	○[a]

Key: ● High effectiveness ⦿ Medium effectiveness ○ Low effectiveness

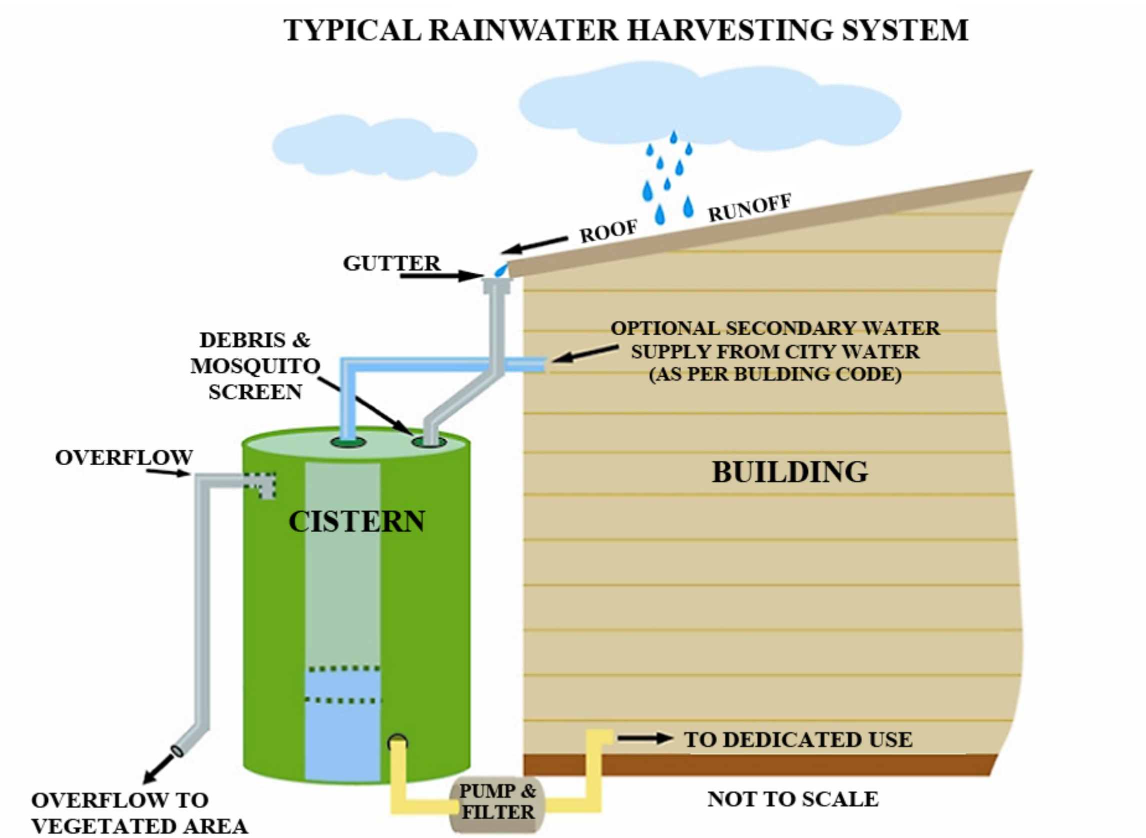
[a] The effectiveness depends on how the water is managed after capture, i.e., slowly released to a storm sewer, used for infiltrating irrigation, etc.

Targeted Pollutants

Sediment	Nitrogen	Phosphorus	Metals	Oil & Grease	Bacteria	Temperature
○	○	○	○	○	○	○

Key: ● High effectiveness ⦿ Medium effectiveness ○ Low effectiveness

Photos and Diagrams



Source: NC Division of Water Quality. Technical Guidance: Stormwater Treatment Credit for Rainwater Harvesting Systems

Figure 3A1-1. Typical rainwater harvesting system

Common Feasibility Constraints and Limitations

- Requires a dedicated plumbing system for indoor use.
- Optimal performance requires active management to ensure that storage containers are emptied between storms.
- Local ordinances can restrict downspout disconnection or indoor use of harvested water.

Runoff Volume and Pollutant Load Removal Estimates

The volume retained in a storm event is determined by the size of the storage container and its available volume at the time of the storm. Careful operation of the system to ensure that cisterns and rain barrels drain completely before a rain event can help to maximize the available volume. The use of real-time control systems can increase performance significantly.

Pollutant removal by rainwater harvesting is minimal, and is generally limited to settling of suspended solids. Water quality can degrade in a cistern if bacteria are allowed to grow.

Practice Design

Sizing is based on rainfall patterns, drainage area, water demand, and space and/or budgetary constraints. Cisterns should be sized to store water from multiple events, or to empty between events, if capacity for back-to-back storms is needed.

Proper cistern capacity is calculated by balancing the expected rainfall volume with the anticipated water demand. Additional capacity could be incorporated to allow extended storage of rainwater for use during dry periods.

Design considerations include the following:

- Piping for harvested rainwater should be labeled to prevent accidental use for potable applications.
- Rain barrels and cisterns should be fitted with emergency overflows.
- Cisterns constructed belowground must be fitted with pumps to deliver collected water.
- Systems for indoor uses such as toilet flushing should be dual piped with potable water for back-up. A backflow prevention assembly should be used to prevent cross-contamination of the potable supply line. Local building codes should be consulted.
- Pretreatment might be desired before storage to prevent fouling of the storage tank. Screening, settling of suspended solids, and oil and grease separation (for parking lot runoff) might be beneficial. The first flush of runoff can be diverted from the storage tank to remove debris.
- Treatment requirements for stored rainwater vary by municipality and intended end use. Typically, no treatment is required for outdoor irrigation, while filtration and/or UV disinfection might be required for indoor nonpotable uses.
- Outdoor cisterns should be screened at each opening to prevent insects from entering.

American Rainwater Catchment Systems Association/American Society of Plumbing Engineers issued *Rainwater Catchment Design and Installation Standards* (August 2009) to assist in properly and safely implementing systems. Several localities have implemented or adopted standards as part of their building codes.

Maintenance Considerations and Resources

A typical maintenance schedule is provided in Table 3A1-2. Maintenance needs will vary by the type of system and location.

Table 3A1-2. Rainwater harvestor maintenance schedule

Activity	Minimum frequency
Inspect and clean filters and screens	Before the first storm event and every 2 months during the wet season
Inspect and clear debris from roof, gutters, downspouts, and roof washers, and other rainwater harvesting areas	Before the first storm event and every month during the wet season
Remove tree branches and vegetation overhanging roof or other above-ground rainwater harvesting areas	As needed
Inspect pumps, valves, and pressure tanks and verify operation	After initial installation and annually at the beginning of the wet season
Inspect cistern(s) and system labeling	After initial installation and annually at the beginning of the wet season
Inspect backflow prevention system	After initial installation and annually at the beginning of the wet season or as required by LACDPH
Cross-connection inspection and test	After initial installation and annually at the beginning of the wet season or as required by LACDPH

Source: Federico, et al. Geosyntec Consultants, *Technical Memorandum: Large-Scale Cistern Standards*, Report to Los Angeles County Department of Public Works, December 2009.

Costs and Factors Affecting Cost

Fifty-five-gallon rain barrels typically cost $50–$100 for prefabricated units, or $30 for do-it-yourself kits.

For cistern tanks, costs depend on the material used for construction, and costs are similar to other water storage tank systems (Table 3A1-3). A tool for estimating tank and pump costs is available from the Water Environment Research Foundation (WERF), the *User's Guide to the BMP and LID Whole Life Cost Model, Version 2.0*, and associated spreadsheet tool.

Table 3A1-3. Cistern tank costs

Cistern tank cost by type ($/gallon, installation not included), 2009			
Fiberglass	**Steel**	**Plastic**	**Concrete**
10,000 gal and up	500-15,000 gal	50-1,500 gal	2,000 gal and up
$ 1.33	$ 2.51	$ 1.43	$ 1.66

Source: WERF BMP and LID Whole Life Cost Model, Version 2.0

Costs for large cistern systems are dependent on many site-specific factors, such as whether excavation is required for underground units. Cost items applicable to systems used for irrigation can include

- Piping and pretreatment (screening)
- Tank, pumps, valves
- Site preparation
- Concrete pad for above ground; excavation for buried

Example system costs are provided in Table 3A1-4.

Table 3A1-4. Summary of cistern system costs with project characteristics

Site	Capacity (gallons)	Construction material	New/retrofit year installed	Location	Estimated cost
Landscape Architecture[a] Library, Tucson, AZ	11,600	Steel and Fiberglass	New 2007	Above-ground	$17,000 (total cost)
Fairmount Square[a] Grand Rapids, MI	30,000	Concrete	New	Buried	$40,000 (total cost)
Redbud Center[a] Austin, TX	31,000	Steel	New 2008	Above-ground	$250,000 (total cost)
Santa Monica Main[a] Library, CA	200,000	Concrete	New 2006	Buried	$700,000 (total cost)
Mark Miller Toyota[b] Salt Lake City, UT	1 @ 8,000 1 @ 2,000	Concrete	New 2008	Buried	$22,000 (total cost)
Hypothetical Office[b] Building, Arlington, VA	10,000	Fiberglass	New 2008	Buried	$179,000 (estimated total)
Open Charter Elementary, Westchester CA[b]	110,000	Modified RainStore3 Infiltration System	New 2004	Buried	$500,000 (not incl. design)
Hall House, Los Angeles, CA[a]	3,600	Polypropylene	Retrofit 1998	Partially Buried	$25,000 (installed)
Center for Community Forestry, Los Angeles, CA[a]	216,000	Concrete	New 2008	Buried	$400,000 (excludes soft costs, distribution system)

[a] Federico et al. 2009. Technical Memorandum: Large-Scale Cistern Standards. Prepared for Los Angeles County Department of Public Works, by Geosyntec Consultants.

[b] Water Environment Research Foundation. 2009. *User's Guide to the BMP and LID Whole Life Cost Model, Version 2.0*.

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1.3 Green Roofs

Description of Practice

Green roofs attenuate flow and provide storage and evapotranspiration of stormwater. They are typically designed with an impermeable membrane that is root resistant, an engineered soil medium, plants, and in many cases an underdrain system. Some green roofs also have leak detection systems. The design of green roof systems significantly affects performance. The two main categories of green roof designs are

- Extensive, which have a shallow planting media layer (typically 2–6 inches) and low-growing, drought tolerant plants.
- Intensive, which have a deeper media layer, and can be planted with a wider variety of plants, including trees and shrubs. Intensive green roofs can be fitted with walkways and used as recreational areas.

Rain falling onto green roofs is both detained and retained in the soil medium. When the soil medium becomes saturated, the excess water percolates through to the drainage layer and is discharged through the roof downspouts. Between storm events, water absorbed by the soil media is returned to the atmosphere by evapotranspiration. Depending on the design and climate pattern of the region, green roofs can provide significant stormwater volume reduction annually, decrease peak flow rates, and help to restore hydrologic function of the watershed by absorbing and attenuating runoff.

In addition to providing stormwater retention, green roofs can be designed to provide ancillary benefits, such as enhancing site aesthetics, urban habitat for birds and insects, reduction of urban heat island effects, insulation value for energy conservation, and increasing the longevity of roofing materials.

Green roofs are common in Europe but have only recently gained popularity in United States as a practice for mitigating stormwater runoff. The *International Green Roofs Projects Database* (www.greenroofs.com) lists more than 1,000 green roof projects, mainly in the United States.

Hydrologic Performance and Targeted Pollutants

Hydrologic Performance

Volume Reduction	Peak Flow Reduction	Groundwater Recharge
●	⦿	○

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Targeted Pollutants

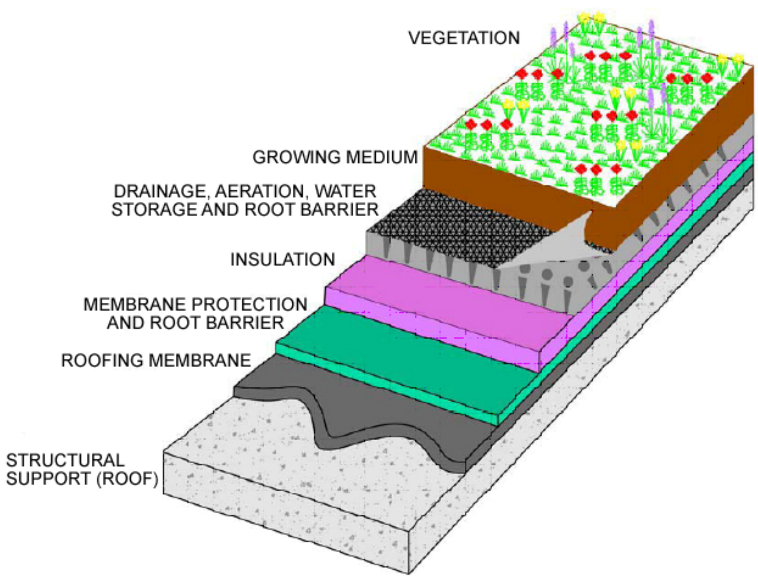
Sediment	Nitrogen	Phosphorus	Metals	Oil & Grease	Bacteria	Temperature
○	○	○	⦿	○	○	⦿

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Photos and Diagrams

Source: The Low Impact Development Center

Figure 3A1-2. ASLA headquarters green roof.



Source: MDE Stormwater Design Manual

Figure 3A1-3. Green roof section.

Common Feasibility Constraints and Limitations

- Slopes when using the more typical construction practices are generally less than 30 percent. Installations on pitched roofs require stabilization structures to prevent migration of the soil medium. Specialized drains are typically required for slopes above 5 percent.

- Roofs must be able to bear the load of a fully saturated medium. Extensive green roof wet weight is approximately 6 to 7 pounds per square foot per inch of depth.
- Construction costs include transporting materials to a roof, which could require a crane.
- Costs of green roof construction are typically higher than other LID practices (such as bioinfiltration or blue roofs) for water-volume reduction. However, it has been shown to be cost-effective when other factors are considered, such as energy savings, and has other benefits to the public, including reduction of urban heat island effect, particularly in dense urban areas (Portland Bureau of Environmental Services 2008).

Runoff Volume and Pollutant Load Removal Estimates

Runoff volume removal is a function of the green roof area, the specifics of the green roof design, and the local climate and rainfall pattern. Green roofs can retain the full volume of small storms, and they are commonly designed to detain brief periods of high-intensity rainfall. Reported results for extensive roofs are summarized in Table 3A1-5.

Table 3A1-5. Performance estimates for annual flow retained, summer flow retained, and peak flow shaving for green roofs

Performance Measure	Performance[a] Estimate	Location	Depth of Media (not including submedia layers)	Source
Annual Flow Retained	50%	Philadelphia	3.5 to 4 inches	USEPA 2009
	75%	Washington, D.C.	3 to 18 inches	Glass 2007
	65%–70%	East Lansing, MI	1 to 2.4 inches	VanWoert 2005
	56%	Portland, OR	5 inches	Portland BES 2008
	26%–86%	National Range	Various	Portland BES 2008
Summer Runoff	95%	Philadelphia	3.5 to 4 inches	USEPA 2009
Peak Flow Shaving	30%–96%	National Range		Portland BES 2008
	60%	Portland, OR	5 inches	Portland BES 2008

[a] Performance as measured over the period as a whole, not for a specific event, for example, not for the 96th percentile storm event, but for that 96% of the total rainfall over the period was retained.

Pollutant removal in green roofs is strongly dependent on the specifics of the design and on rates of atmospheric deposition. Studies have shown that green roofs do not often provide pollutant reductions; however, it is noted that the concentration of pollutants in direct rainfall is very low (therefore, there is relatively little pollutant to remove). Temporary export of nutrient can occur during initial establishment of the media and plants. Poorly designed green roof soil media can lead to export of low concentrations of nutrients and solids from the media, fertilizer and plants. For this reason, it is preferable to discharge the runoff from green roofs into bioretention or other unit if pollutant reduction is needed in addition to the volume reduction (EPA 2009). Green roofs, however, have been shown to export lower levels of pollutants than conventional roofs. Material selection is an important consideration. Many roofing materials can export toxic chemicals used in their construction (Clark et al. 2008).

Practice Design

Green roofs are most often constructed on flat or shallow sloped roofs, but roofs with slopes up to 30 percent accommodate green roofs with the use of mesh, stabilization panels, or battens. The area covered by green roofs is typically limited to 50–80 percent of the total roof area because of the need to accommodate HVAC (heating, ventilation, and air conditioning) or other equipment (e.g., cell towers or solar panels) and roof access or other penetrations. Green roofs have also been designed to accommodate solar panels.

A typical green roof profile would include the following layers:

- Vegetation layer
- Engineered growth media
- Separation geotextile
- Semi-rigid plastic geocomposite drain or mat
- Root barrier
- Waterproofing membrane

Plant selection—Plant selection varies depending on the type of green roof installed. Extensive green roofs should be planted with low-growing, drought-tolerant plants, such as succulents. Sedums are frequently used. Intensive green roofs, which have deeper soil media, can accommodate a much wider variety of plants, including trees and shrubs. Intensive green roofs often require irrigation to support the larger plants.

Soil medium—To minimize the potential for nutrient export, the soil medium should have a high mineral content. Use of compost has been found to produce elevated levels of nitrogen and phosphorus in effluent, at least in the short term (Moran et al. 2004).

Maintenance Considerations and Resources

Maintenance requirements vary depending on design specifics, with extensive green roofs typically requiring less maintenance than intensive green roofs. Maintenance typically includes

- Periodic irrigation during plant establishment and dry periods.
- Periodic weeding, fertilization (if needed), and infill planting
- Periodic inspection of drainage outlets and waterproof membrane.

Costs and Factors Affecting Cost

Costs depend on the media depth, the number and type of additional structural components in the design, the vegetation selected, and the need for structural roof modifications. Costs for extensive green roofs typically range from $8–$14 per square foot (PADEP 2006). The installation cost of the green roof is partially offset by increasing the life of the underlying roof and reducing heating and cooling demand within the building.

Costs were reported to vary primarily by the installation type (WERF 2009; Portland BES 2008):

- Modular, tray-type installations: $19.50 per square foot
- Custom applications with media spread across the surface: $8.75 per square foot

Green roofs reduce energy costs and extend roof life. *Green Roofs for Healthy Cities* (www.greenroofs.org) provides a calculator to estimate the long-term savings.

A cost-benefit analysis of a hypothetical green roof concluded that green roofs had a higher net present value for the owner and the public, despite higher initial capital and O&M costs (Portland BES 2008). Not all benefits were examined, but areas where economic benefits accrued include

- For the public: (1) Reduced Stormwater Quantity; (2) Avoided Stormwater Infrastructure; (3) Improved Air Quality; (4) Enhanced Habitat
- For the owner or developer: (1) Reduced Stormwater Fees; (2) Extended Roof Life; (3) Increased floor-to-area (FAR) allowance allowing more floors and higher buildings; (4) Reduced energy costs

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1.4 Blue Roofs

Description of Practice

A blue roof is a roof design that is explicitly intended to provide temporary storage and slow release of stormwater runoff. In many locations, these approaches are also referred to as *rooftop detention*. They are most commonly used in dense urban areas where other methods of stormwater detention are impractical. Blue roofs are used to detain rooftop runoff on-site and reduce the rate of runoff from rooftops during rainfall events. A blue roof can be used as a standalone detention method. Or, because they do little to improve the water quality of runoff, they can be part of a treatment train that includes other LID and conventional BMPs such as bioretention, infiltration, or wetland systems to shave peak flows and provide temporary storage to enhance the function, improve the performance, and reduce the cost of those practices. Blue roofs are one of the least expensive means for temporarily detaining stormwater on-site and can be used where green roofs are not feasible, cost effective, or otherwise desired because of competing needs.

The four primary blue roof types are described below:

- *Roof-integrated Designs*—Roof-integrated designs are built during new construction or as modifications of existing roofs to intentionally store standing water over extended periods.

  These designs use a roofing membrane or waterproofing system as the primary water detention structure. Therefore, water is temporarily ponded directly on the roof surface. Roof integrated designs can be designed to store water as an open water surface or partially or completely within a porous media.

  In addition, structures such as walkways, decks, or plazas can be constructed on top of roof integrated designs to minimize the impact of ponded water on roof access. Alternatively, porous media such as flexible paving tiles or granular media can be used as a permeable walking surface on all or part of the roof to allow for access, while reducing the amount of standing open water.

  Roof-integrated designs can be constructed as a secondary roofing layer on top of an existing surface in the same manner as a physical root barrier in green roof designs.

- *Modular Tray Designs*—Modular tray systems use plastic trays to temporarily detain water during rainfall events and release this water over some period following a rainfall event. This approach provides flexibility in both the size and configuration of the detention system and is, therefore, well-suited for retrofit designs. Equipment and other roof penetrations can be avoided through selective placement of the trays. Loading issues can be addressed through optimal density and placement configurations. The trays can be physically attached to the roof or underlying supporting grid and/or held in place with ballast composed of coarse stone or other weighted materials. The depth of the ballast or media contained in the trays can be varied depending on the desire to reduce the presence of open water surfaces.

  Modular trays can have any number of different outlet designs according to the goals of the installation (e.g., reduce peak flows, achieve specific lag time for target events). When the water is released, the drainage system for the existing roof continues to function as it did before the retrofit (i.e., hydraulic head and flow depths on the roofing surface during rainfall are not increased).

Modular tray blue roof designs can be selectively mixed with green roof components to improve aesthetics and provide some of the additional benefits of green roofs. The most challenging component of blue roof tray designs is the robustness of the hydraulic outlet design. Consistent and reliable drainage of the trays with little maintenance is a key consideration. Some designs allow for trays to be interconnected to effectively act as a larger tank.

- *Roof-Dams/Roof-Checks*—Roof-dams or roof-checks are impermeable or semi-permeable interim breaks in the surface flow paths installed on existing or new roofs that allow water to pond behind them as temporary detention. The dams can incorporate specific overflow or outlet designs to slowly release the stored water. In the same manner as a roof-integrated design, the roof is used as the primary water detention structure with the flows being restricted by the roof-dams. If retrofit onto existing roofs, the ability of the roof to accept additional ponding should be assessed and addressed. In older roof installations, new roofing and additional water proofing might need to be installed in conjunction with the installation of the dams.
- *Actively Controlled Systems*—Blue roofs that are used for temporary rooftop storage can be classified as *active* or *passive* depending on the types of control devices used to regulate drainage of water from the roof. Passive designs use hydraulic structures such as weirs, orifice plates, or hydraulic regulators to control release rates from the roof. Active approaches allow for the use of a valve configuration and controller to regulate discharge of flows from rooftops.

  The simplest design for an actively controlled blue roof is the retrofit or installation of a pneumatically or hydraulically actuated pinch valve on the roof leader drain pipe. This valve can be connected to a low cost micro-controller, which monitors hydraulic head on the valve and timing of storage on the roof surface. The controller can be programmed to release the ponded water according to some predetermined optimal approach on the basis of analysis of the receiving storm sewer, downstream BMP, or receiving water. More complex designs can integrate communications with server-side and/or Internet-based data feeds, or telemetry to optimize release timing and quantities.

Blue roofs can be implemented effectively on shallowly sloped roofs in residential, manufacturing, commercial, or industrial settings. Rooftop detention is a particularly good storage option in densely developed areas where roofs make up a significant portion of the total site area.

Blue roofs are well-suited to applications on commercial and residential buildings, which typically have large, flat roofs and little or no area available for storage on site surrounding the building. Such large roofs generate significant runoff quantities. Rooftop detention using blue roofs represents a cost effective and convenient storage option that can be applied to new construction in the urban environment to provide adequate storage volume and runoff reduction to comply with stormwater regulations.

In addition to applications in densely developed areas, blue roof storage techniques also lend themselves well to implementation on sites with moderate to large flat roofs where flow from impervious non-roof area (e.g., parking lots, walkways) also contributes to the total runoff. In these situations, blue roofs are used to control rooftop runoff, while subsurface BMPs are used to control runoff from non-roof areas. The use of rooftop storage on such sites reduces the required volume for subsurface systems and allows these systems to be constructed over a smaller area.

Key advantages include

- Often the least expensive means for temporarily storing stormwater at a site particularly when compared to subsurface storage or green roof systems
- Can reduce the size and/or improve the performance of downstream BMPs, such as bioretention cells of infiltration systems
- Easy to install—no additional excavation is required, additional construction could be minimal depending on the depth of water to be stored
- Existing commercially available products for flow control
- Readily coupled with other storage techniques, such as subsurface or surface storage

Hydrologic Performance and Targeted Pollutants

Hydrologic Performance

Volume Reduction	Peak Flow Reduction	Groundwater Recharge
○	●	○

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Targeted Pollutants

Sediment	Nitrogen	Phosphorus	Metals	Oil & Grease	Bacteria	Temperature
○	○	○	○	○	○	○

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Photos and Diagrams

Source: with permission from the New York City Department of Environmental Protection

Figure 3A1-4. Rooftop detention being used to control runoff at a commercial property.

Common Feasibility Constraints and Limitations

- Storage using outlet controls limited to flat roofs or roofs with shallow slopes (e.g., < 1 percent) because of increased ratio of ponding depth to available volume for steeper slopes. This problem can be addressed through the use of modular tray designs or roof-dams.
- Limited benefit on sites where roof area makes up only a small portion of total impervious area.
- Regular maintenance varies by design, but is an important consideration. Verification of system performance might be necessary.
- Potential tampering must be considered in design.
- Pest problems must be avoided through proper design and maintenance, e.g., mosquitoes.
- Local building codes should be checked to ensure designs are compliant.

Because blue roof designs generally hold less than 4 inches of ponded water on the roof for times ranging from a few minutes to many hours, blue roofs typically do not impact the availability of roof space for other uses.

If such water ponding is incompatible with anticipated future uses of the roof, the blue roof can be designed to occupy a portion of the roof area, leaving additional roof space available for other purposes. If structures and equipment are mounted to the roof within the area intended for ponding water, it might be necessary to provide additional waterproofing around the structure or equipment or to elevate the equipment above the anticipated maximum water depth to prevent damage and provide access for maintenance. Where roofs are intended to be used as means of egress or points of rescue for fire safety, walkway pavers should be provided to allow for safe passage to fire escapes from the roof surface. The pavers provide a dry walking surface to allow for safe movement through ponded water. In addition, decks, walkways or pavers can be incorporated into the design of a rooftop detention system to provide space on the rooftop for passive recreational use.

The application of blue roof systems is most effective on roofs with a maximum slope of about 1/8 inch per foot (or 1 percent slope) or those with drainage configurations that can safely allow for the necessary volume detention.

To prevent clogging, the owner should inspect drains and clear snow and ice as necessary after winter precipitation events in accordance with established maintenance procedures. As with conventional flat roofs, maintenance procedures for blue roof systems include the removal of accumulated snow before an anticipated rain event to prevent possible overloading. Homeowners or building maintenance staff can remove snow from the blue roof using the same removal methods used for conventional flat roofs.

Runoff Volume and Pollutant Load Removal Estimates

Blue roofs primarily provide a means for temporarily detaining water. Little direct impact on water quality can be achieved through the use of blue roofs alone. Some evaporation will occur in systems that detain water for extended periods. Evaporation rates on blue roofs approach pan evaporation rates. Pan evaporation rates can be significant under certain climatic conditions (e.g., hot, windy, low humidity days).

Practice Design

Blue roofs are most often constructed on flat or shallowly sloped roofs, but tray and roof dam designs can be used on slopes in excess of 5 percent. On roof integrated designs where the roof is sloped, even very shallow slopes dramatically reduce detention capacity. Typically in retrofit situations, the roof is reconstructed as a part of blue roof installation. With tray designs, that might not be necessary. The designer must pay close attention to roof system manufacturer's requirements to ensure that the roofing system and design are compatible with manufacturer's warrantees and with the blue roof design.

Maintenance Considerations and Resources

Maintenance for most blue roof systems are similar to those required for typical flat roofing drainage systems and involve occasional snow and ice removal, regular inspection for debris clogging inlets, and inspection and repair of the roof.

Costs and Factors Affecting Cost

Blue roofs are one of the least expensive means for temporarily detaining stormwater on-site. The marginal cost of adding a blue roof to new construction is typically less than $2 per gallon of temporary storage where structural modifications to building design are not required (e.g., designs take into account snow loads). As new approaches (e.g., tray designs) gain wider acceptance in the marketplace, it is expected that blue roof detention can drop below $1 per gallon of temporary storage.

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1.5 Bioretention/Biofiltration

Description of Practice

Bioretention cells are small-scale, vegetated, shallow depressions that are used to reduce runoff volumes and pollutants through the process of soil filtration, interception, vegetative uptake, biological processes, infiltration, retention, and evapotranspiration. Bioretention cells can be used as stand alone systems or as part of a treatment train. Bioretention cells are typically designed with native soils and or/an engineered soil mix, and plants that are selected to be tolerant of a range of wet and dry conditions. In some cases site conditions or design goals might require the use of gravel for additional volume retention or the use of overflow devices. Where groundwater recharge is required, bioretention can help protect the quality of infiltrated stormwater. Bioretention typically has no underdrain or liner, both significantly reduce volume reduction performance.

Biofiltration allows for an underdrain, with only partial or no infiltration achieved, for applications such as where a discharge is desirable or infiltration is to be avoided.

The use of soil-based, vegetated systems have distinct advantages over the use of nonbiological infiltration trenches or similar designs for the following reasons (Davis et al. 2009):

- Roots promote media permeability.
- Surface vegetation can be used to slow stormwater flows and filter sediments.
- Roots support microbial populations needed for pollutant biodegradation.
- Phytoremediation uptakes and breaks down pollutants.

It is recommended that, where feasible, designs use a variety of hardy native plants that are adapted for both wet and dry soil conditions to ensure long-term plant survival and vigor. If native plants are not available, the use of nonnative, noninvasive species that typically do not require fertilizer, irrigation or pest control except at establishment is appropriate.

Bioretention cells can be used in a wide set of applications in the built environment to manage runoff from roofs, lawns, and streets and other impervious areas such as parking lots and sidewalks. Bioretention practice typically fall in to the following categories:

- Residential rain gardens
- Tree boxes (common and expanded) and shrub bioretention cells
- Sidewalk or right of way planter boxes
- Parking lot islands
- Street curbs extensions and bump-outs.
- Wooded bioretention areas
- Bioretention swales

Hydrologic Performance and Targeted Pollutants

Hydrologic Performance For Design Storm Events

Volume Reduction	Peak Flow Reduction	Groundwater Recharge
●	●	●

Key: ● High effectiveness ◉ Medium effectiveness ○Low effectiveness

Targeted Pollutants

Sediment	Nitrogen	Phosphorus	Metals	Oil & Grease	Bacteria	Temperature
●	◉	◉	●	●	◉	●

Key: ● High ◉ Medium ○ Low

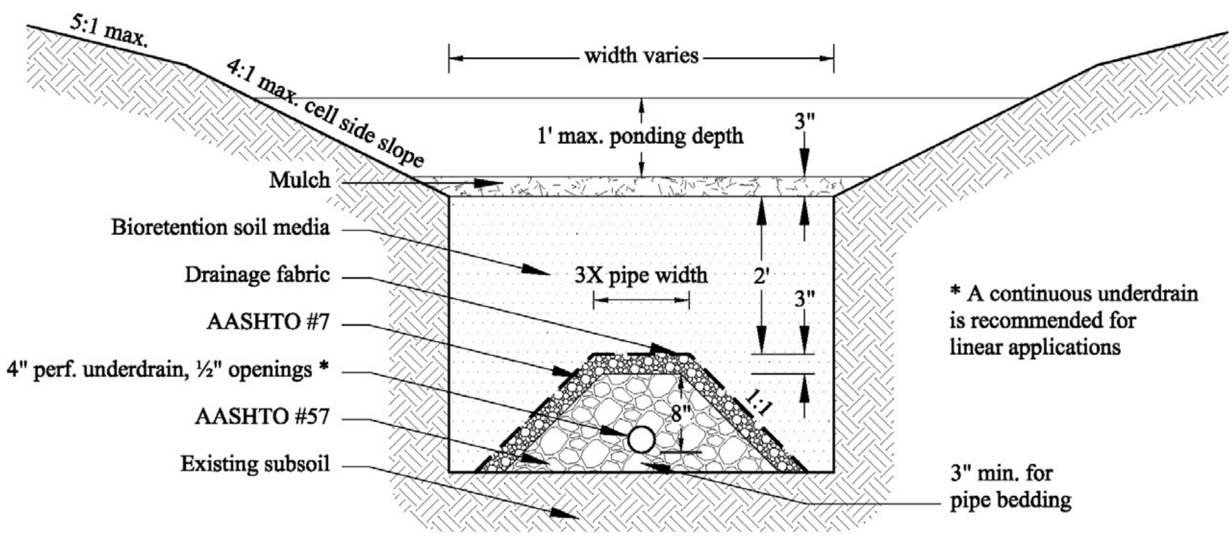
Photos and Diagrams

Source: Larry Coffman, Prince George's County, Somerset Subdivision

Figure 3A1-5. Bioretention cell for street and yard drainage.

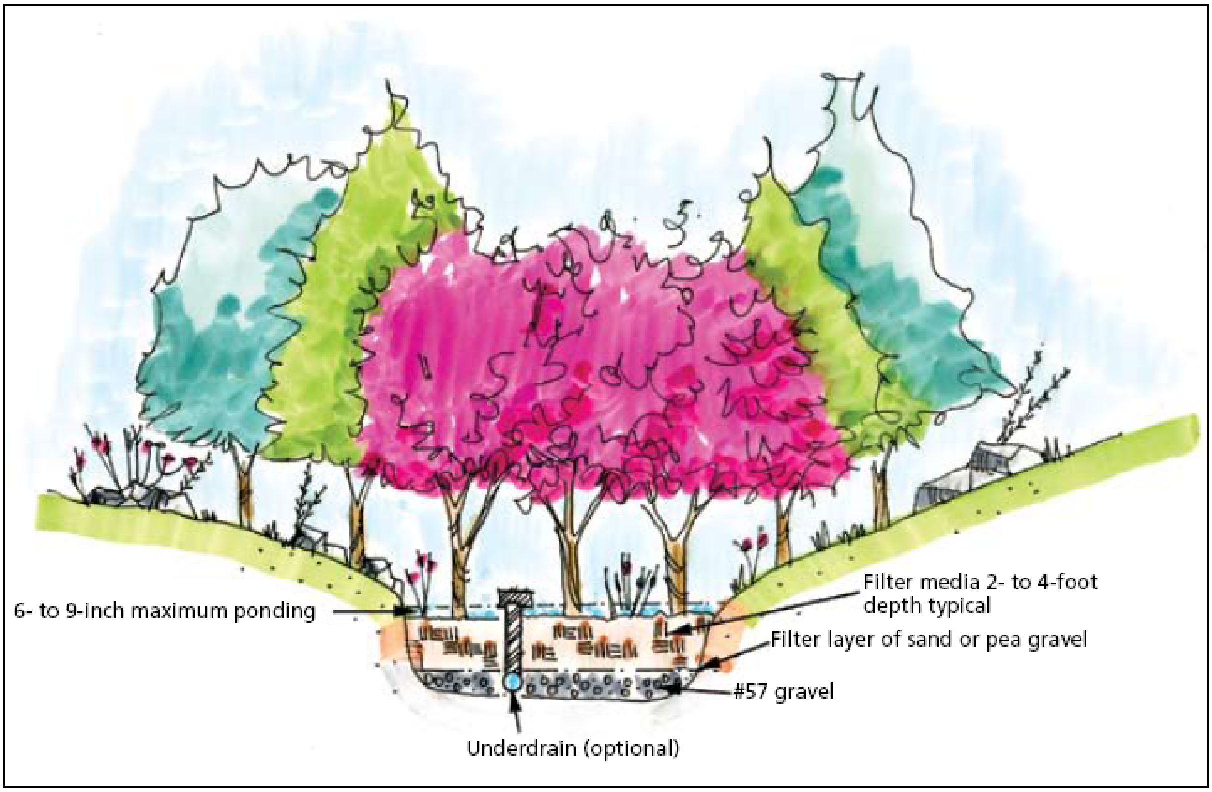
Source: Abby Hall, USEPA

Figure 3A1-6. An urban bioretention system treats sidewalk and road runoff.



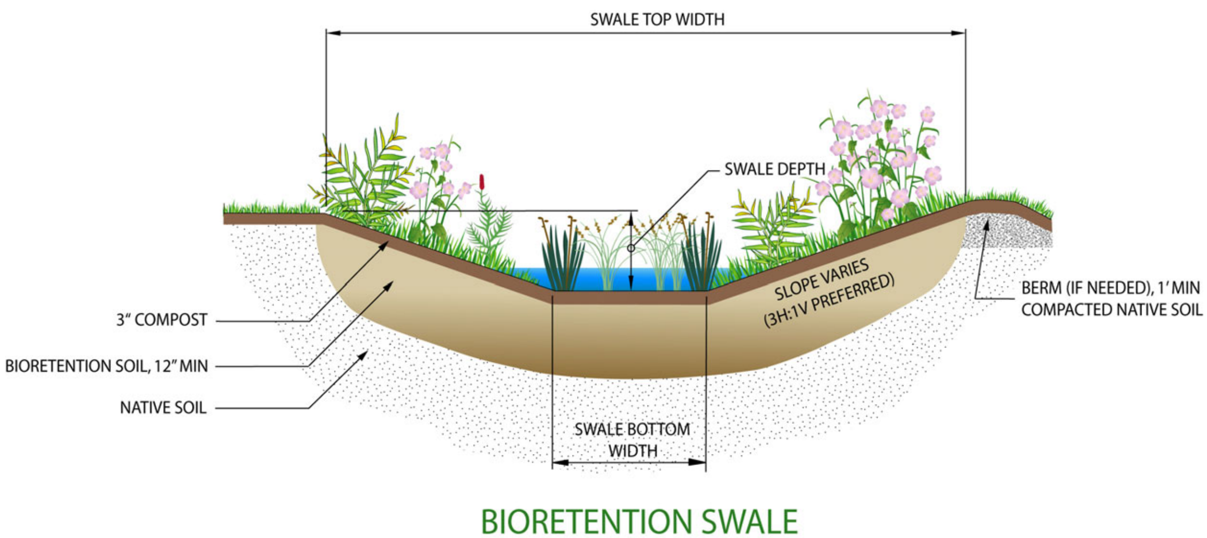
Source: LID Center

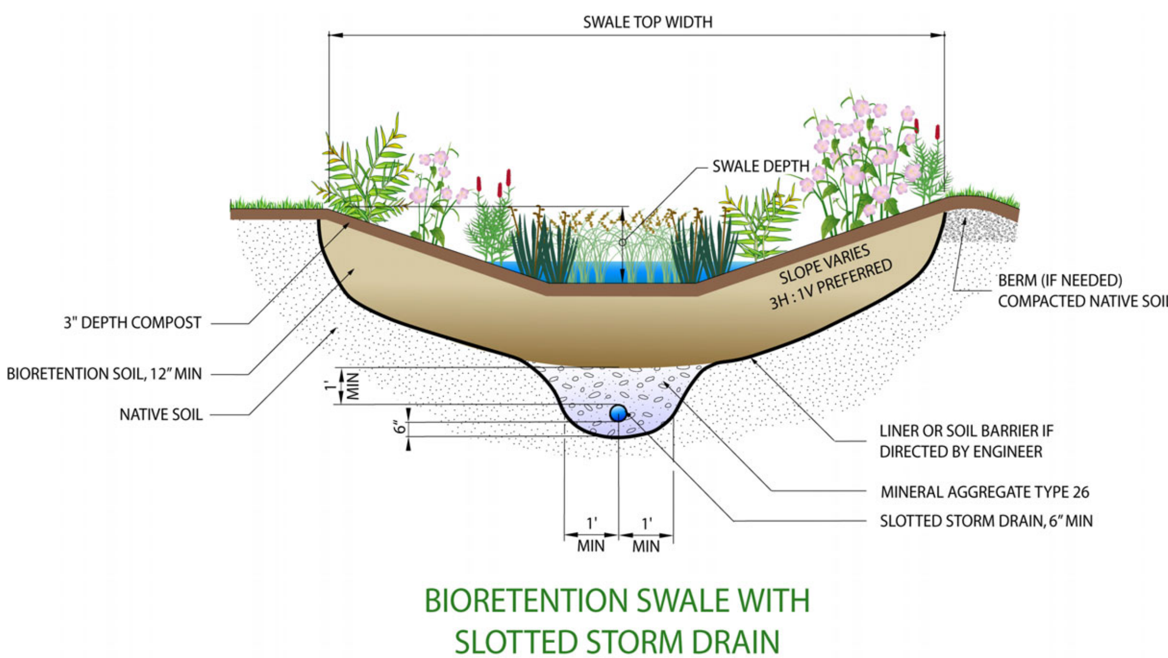
Figure 3A1-7. Typical bioretention cell cross-section. Not to scale.



Source: Urban Watershed Forestry Manual, Part 2, CWP and USDA, 2006

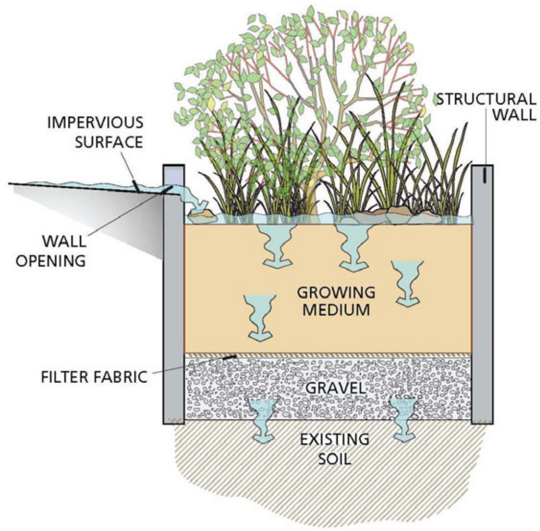
Figure 3A1-8. Wooded bioretention can increase pollutant uptake and requires specific design modifications for tree growth and avoiding engineering conflicts.





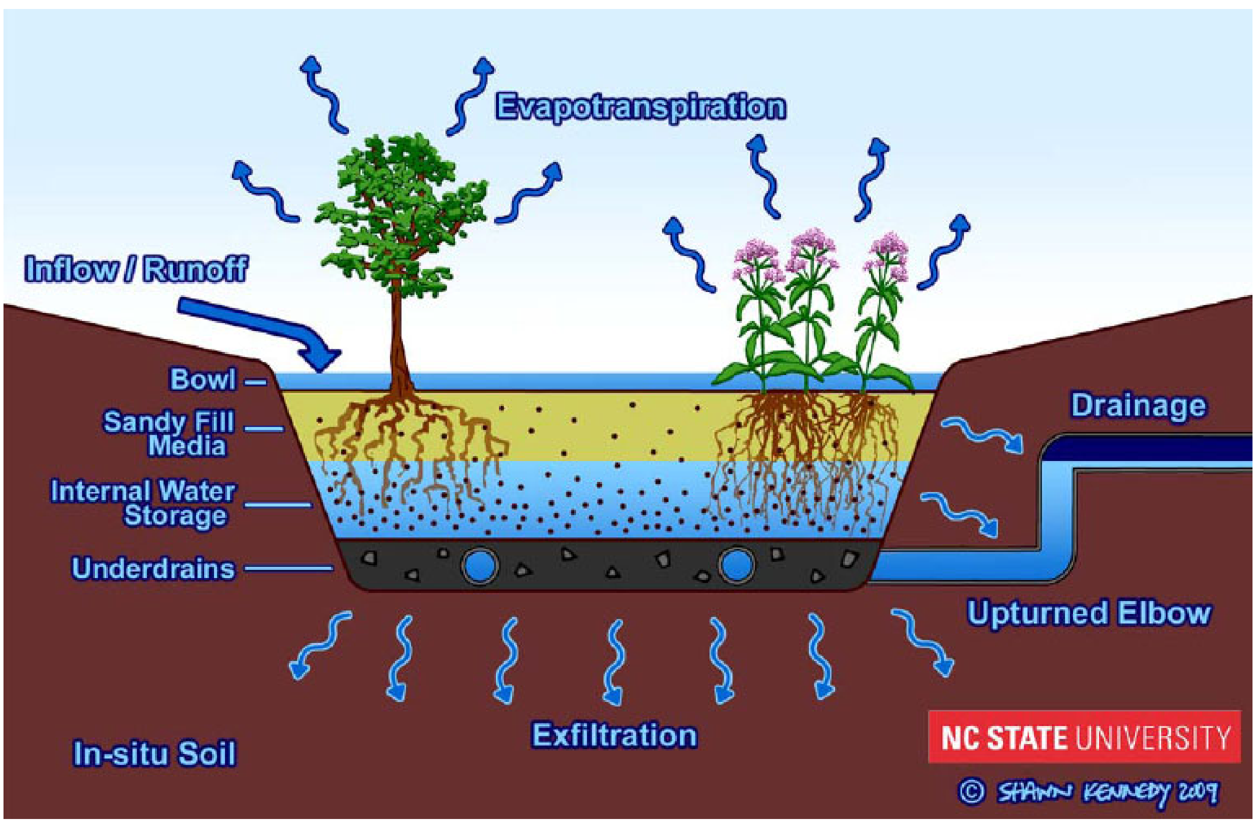
Source: Seattle Public Utilities

Figure 3A1-9. Bioretention swales with and without underdrain.



Source: Portland Bureau of Environmental Services

Figure 3A1-10. Infiltration planter box.



Source: Brown 2009

Figure 3A1-11. Bioretention with internal water storage volume.

Common Feasibility Constraints and Limitations

Bioretention practices should not be used in some applications, including

- Slopes are greater than 20 percent
- *Hot spots* that have a high potential for groundwater contamination, e.g., gas station runoff or areas where chemicals are stored or managed
- Large drainage areas from impervious areas greater than 15,000 square feet (unless a system of separate cells is used to manage the runoff)
- Areas of shallow bedrock or high water tables where infiltration is not feasible (note: design modification can be used to compensate for these conditions where surface retention is desired)
- Applications that have high sediment loadings unless use pretreatment systems and/or increase maintenance

Stormwater infiltration can affect groundwater quality; however, the incidence of groundwater contaminated to an unhealthy level from stormwater is low. Many factors contribute to the risk (Clark et al. 2009).

Estimated Effectiveness for Runoff Volume and Pollutant Load Reduction

Volume Reduction. The amount of volume reduction achievable is a function of design; for example, selecting a storm depth and designing the cell to capture this volume in the ponding area and upper soil void space. To determine the annual volume reduction achieved, the likelihood for back-to-back storm events and seasonal temperature variations should be considered, and continuous modeling is used for this analysis (USEPA 2008). Guidance manuals are referenced in this fact sheet, and by state and local jurisdictions, that provide instruction on methods for calculating volume reduction on the basis of infiltration rates and storage volumes. Evapotranspiration also provides some volume reduction. The following factors influence the annual stormwater volume reduction achievable:

- Local climate and rainfall patterns.
- Local soil characteristics, including the soils underlying the constructed bioretention cell.
- Local evapotranspiration rates driven by climate conditions, vegetation type, and length of growing season.
- Site conditions such as location in a sunny area or in deep shade.
- Ratio of cell media volume to drainage area. Increasing the volume of media relative to the drainage area has been demonstrated to reduce outflow.
- Use of underdrains or liners or both versus infiltration to underlying soil. The use of underdrains or liners can significantly reduce volume reduction performance. If an underdrain is used, adding an internal storage zone below the underdrain improves performance, allowing more time for infiltration, and potentially denitrification (see Figure 3A1-11).
- Care during construction to ensure construction site erosion does not clog the system.

Pollutant Reduction. Pollutant concentration reductions can be obtained through biofiltration to further reduce overall loading. Many factors associated with the pollutants, water, soil, plants, microbes, and system design affect pollutant removal performance.

For example, nutrient removal can be influenced by the following factors:

- The amount of organic material and the potential for the media to decay and leach nutrients
- The form of phosphorus or nitrogen as it enters the cell, and transforms in the cell
- Biological transformation of nutrients in microbial and plant processes
- Cation exchange capacity and ability to sorb nutrients
- The presence of an anaerobic/saturated zone which influences denitrification potential
- Soil media composition and volume
- Plant species, community composition, size, coverage and health

Phosphorus removal requires the use of a low phosphorus index soil mix with a high cation exchange capacity (Li et al. 2009). Layering of media targeted at specific pollutants can enhance water quality benefits (Li et al. 2009).

A summary of some pollutant specific removal information is provided below (Davis et al. 2009):

- *Suspended Solids*—Reductions can be as high as 99 percent. New facilities might initially export TSS from the washout of fines in the media.
- *Phosphorus*—Reduction is highly variable, typically from 50 to 80 percent. Effluent phosphorus at some locations has been higher than influent concentrations, largely because of high initial levels of soil phosphorus.
- *Nitrogen*—Because of the complex interactions of nitrogen species, total nitrogen removal is difficult to achieve. Nitrogen removal might be increased with the use of a higher percentage of organic matter in the soil mix (Hinman et al. 2005), provided the organic matter does not contain high nitrogen concentrations. Bioretention can remove organic nitrogen in the media’s organic material. Nitrate, however, is very mobile, and only when the media remains saturated for an extended period denitrification possible.
- *Heavy Metals*—Dissolved and particulate-bound metals are removed by filtration of particulate metals and adsorption of dissolved species in the mulch and bioretention media. Metals have been shown to be primarily removed in the first 1 to 2 inches of the surface mulch layer (Hinman et al. 2005).
- *Oil & Grease*—Adsorption of low concentrations of motor oil to organic material in the soil mix have resulted in removal efficiencies of 96–99 percent. Native bacteria in the mulch can biodegrade the hydrocarbons over time.
- *Chlorides*—Bioretention does not treat chlorides and, where exposed to salting practices, has been found to leach chlorides year round.

- *Bacteria*—Removal of bacteria have been monitored to be between 70 percent (Hathaway and Hunt 2008) and 91 percent, through process that include filtration, drying, and exposure to sunlight.

The reductions in mass loading of nitrogen and phosphorus achievable with bioretention have been shown to be a result of the decrease in runoff volume, not necessarily decreases in concentration. Field tests have shown considerable mass reductions to be achieved even when increases in concentrations occur across the bioretention cell from nutrients contained in the media (Hunt et al. 2006). For this reason, a volume reduction performance goal is recommended. Understanding the ranges of effluent concentrations observed, though, is valuable to evaluate performance.

Typical influent and effluent concentration ranges. The range of observed concentrations of nutrients in stormwater runoff in the National Stormwater Quality Database is provided in Table 3A1-6 to give an indication of influent concentration ranges.

Table 3A1-6. Selected median concentration of nitrogen and phosphorus pollutants from urban land uses

	NH_3 (mg/L)	$N0_2$+NO_3 (mg/L)	Nitrogen, Total Kjeldahl (mg/L)	Phosphorus, total (mg/L)
Residential	0.32	0.6	1.4	0.3
Commercial	0.5	0.6	1.6	0.22
Industrial	0.5	0.73	1.4	0.26
Freeways	1.07	0.28	2	0.25
Open Space	0.18	0.59	0.74	0.31

Source: Pitt, R., A. Maestre, and R. Morquecho. 2004. The National Stormwater Quality Database (NSQD, version 1.1). University of Alabama, Department of Civil and Environmental Engineering, Tuscaloosa, AL. http://rpitt.eng.ua.edu/Research/ms4/Paper/Mainms4paper.html. Updated February 16, 2004. Accessed February 3, 2010.

For effluent quality from bioretention, the following are noted:

- Effluent concentration goals of the *New York State Design Manual*, Chapter 10 Enhanced Phosphorus Removal (Quigley et al. 2008)
  - less than or equal to 0.1 mg/L TP
  - less than equal to 0.06 mg/L dissolved phosphorus
- Reported effluent concentration results from field studies in the mid-Atlantic (Davis et al. 2009)
  - from 0.06 to 0.56 mg/L TP
  - from 0.08 to 2.8 mg/L TN

Cold weather performance. Bioretention can provide effective infiltration in cold weather. Dietz and Clausen (2007) report that, despite measureable frost, 99 percent of runoff was either evapotranspirated or infiltrated for bioretention in Connecticut. The University of New Hampshire reports similar favorable performance in winter conditions (Roseen et al. 2009), and rapid thawing of bioretention media is reported when runoff enters.

Summaries of Volume and Pollutant Loading Reductions Achievable

The volume reduction achievable is based on the system design and local climate pattern. Systems can be design to retain and infiltrate a specific storm depth, with the excess volume either bypassing or overflowing the system. To determine the annual volume reduction achieved, continuous modeling can be used. For example, in *Stormwater Best Management Practices (BMP) Performance Analysis* (USEPA 2008), performance curves are generated on the basis of a given design specification, the soil infiltration rate, depth of runoff treated, and land use type for a specific climate area, in this case the New England region. Using that approach, it is possible to select a design storm to approximately achieve a desired annual volume reduction goal.

A wide range of performance results have been observed in field tests, and authors cite the difficulty of using such data to prepare general performance estimates (Dietz 2007; Li and Davis 2009; Davis et al. 2009). Volume reductions from 75 percent to greater than 90 percent on an annual average basis have been reported with bioretention (Geosyntec Consultants, *Urban Stormwater BMP Performance Monitoring,* International Stormwater BMP Database, WERF/ASCE/EPA 2009); these values typically reflect precipitation patterns of the study area where most of the annual rainfall occurs in small events of approximately an inch depth or less. For understanding and comparing performance results, estimates should be for an annual basis using long-term, region-specific weather data for a specific design scenario.

Performance estimates provided in Table 3A1-7 for hypothetical average bioretention installations in the Chesapeake Bay watershed lead to the following observations (Simpson et al. 2009):

- The majority of the load reduction is from runoff reduction, therefore reporting the runoff reduction component is essential for understanding system performance (Center for Watershed Protection and Chesapeake Stormwater Network 2008).
- Volume reduction can be a surrogate for, or approximate indicator of, the pollutant removal achieved.

Practice Design

Several design considerations influence the overall performance of bioretention, including

- The potential for clogging should be assessed and pretreatment, such as mulch, should be provided if necessary. If grass swales are used, care should be taken to ensure that sediment will not accumulate to the point where it overtakes the vegetation and becomes costly to remove.
- Well-draining soils allow for rapid infiltration, but if the infiltration rate is too rapid, nitrate can pass though without treatment.
- Soils with slow infiltration rates can decrease the overall stormwater volume retention. Infiltration tests at the site should be performed to better estimate expected performance. In these conditions, if a specified volume is to be retained, the designer should consider designing the subbase with gravel or other materials to retain the requisite volume.
- When conditions necessitate the use of underdrains the discharge rate should be as slow as feasible to maximize infiltration. Overflows are preferred to maintain maximum infiltration. Other options include positioning the discharge orifice above the bottom of the invert, with an upturned elbow outlet configuration (Brown 2009).

Table 3A1-7: Generalized bioretention performance estimates for the Chesapeake Bay Area demonstrate that the majority of the load reduction is from runoff reduction

Bioretention	EMC-based removal (PR)			Runoff reduction (RR)	Mass-based removal (TR) expressed as removal from collection area (acres)		
	TP	TN*	TSS		TP	TN	TSS
C/D soils, underdrain	37	10	50	15	45	25	55
A/B soils, underdrain	37	10	50	65	75	70	80
A/B soils, no underdrain	37	10	50	80	85	80	90
					±20	±15	±15

Source: Simpson and Weammert 2009.

Notes:

1. Soil classification (A, B, C, D) per USDA National Resource Conservation Service (NRCS)
2. Event Mean Concentration-based Removal expressed as Percent Reduction (PR)
3. Mass Based Removal expressed as percent removal of total load by mass (TR)
4. Nitrogen concentration reduction is low potentially because the solubility of nitrate, the potential for organic nitrogen and ammonia to mineralize in the bioretention media to the nitrate form, and the lack of conditions needed for denitrification contribute to nitrogen export.
5. Assumptions included: 1) highly impervious urbanized land use; 2) generalized for design criteria typical of Bay area jurisdictions; 3) designed, installed and maintained by persons who are not experts in bioretention; 3) low phosphorus soil media; 4) for systems designed for a 1” storm, rain events from 1” to 1.5” depth will begin to show overflow
6. Total removal estimated by the calculation TR = RR + {(100-RR) * PR)}, rounded to a factor of 5.
7. Authors caution that the estimates, based on limited data and generalized for simplicity, might not represent true long-term performance throughout the watershed. Performance is highly variable even under controlled conditions.

- An impermeable liner, with an underdrain, can be used to prevent infiltration of stormwater from the biofiltration cell, for example, if soil contamination is suspected. These systems provide water quality improvements because of the pollutant reductions available from the vegetated system and moderate volume reductions from evapotranspiration.

Maintenance Considerations and Resources

Typical maintenance activities are as follows:

- Supplemental irrigation might be needed during the first 2 to 3 years after planting. Drought-tolerant species might need little additional water after this period, except during prolonged drought, when supplemental irrigation can become necessary for plant survival.
- Weeds should be removed by hand until vegetation is established. Although plants might need pruning to maintain healthy growth, routine mowing should not be required. Dead or diseased plants should be removed and replaced. Mulch should be re-applied when erosion is evident to maintain a 2–3 inch depth.
- Inspect at least two times per year for sediment buildup, trash removal, erosion, and to evaluate the vegetation. Sediment should be removed in a manner that minimizes soil disturbance if

buildup reaches 25 percent of the ponding depth. Ensure pretreatment devices, if used, are maintained.

- Some manuals recommend replacing the top few inches of bioretention media every few years and/or when infiltration rates slow down too much.

Costs and Factors Affecting Cost

Costs vary according to many factors including soil depth, plant selections, slope conditions and the contractor's familiarity with the practice. Typically costs are (WERF 2009, *User's Guide to the BMP and LID Whole Life Cost Model, Version 2.0*, and associated spreadsheets)

- For residential rain gardens: Between $6 per square foot (installed by the owner) to $16 per square foot of rain garden surface area (professional installed).
- For urban curb-contained bioretention, $16–$29 per square foot, driven by the cost of curbing and other urban-related infrastructure that can be used for conventional landscaping.
- Bioretention cells often replace areas that would have been landscaped, so the life-cycle cost can be less than the landscaped alternative.

Some factors influencing costs are

- Material availability and transport
- Site conditions (e.g., traffic, utilities)
- Underdrains that might be selected if the subgrade soils infiltrate poorly; an overflow is typically less costly while providing better volume-removal performance
- Specific stormwater management requirements, such as enhanced nutrient removal
- The need for, and the type of, pretreatment
- Vegetation type and scale
- Soil medium specifications and availability
- Size of installation

The Prince George's County *Bioretention Manual* (2007) and WERF's *BMP and LID Whole Life Cost Model* (2009) provide reported costs and templates to facilitate project cost estimation.

Example Bioretention Design Manuals in the Chesapeake Bay Watershed Area

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Pennsylvania Stormwater Best Management Practices Manual, BMP 6.4.5 Rain Garden/Bioretention, 2006.

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1.6 Infiltration

Description of Practice

Infiltration practices use temporary surface or underground storage to allow incoming runoff to exfiltrate into underlying soils. By diverting runoff into the soil, infiltration practices not only reduce the volume of runoff discharged from the site, but also help to preserve the natural water balance on a site and can recharge groundwater and preserve baseflow. Because of that, infiltration practices are limited to areas with porous soils (generally where measured soil permeability rates exceed one-half inch per hour) and where the water table or bedrock are well below the bottom of the practice.

Infiltration practices can be used at three scales: micro-infiltration, small-scale infiltration, and conventional infiltration (VA DCR 2010).

- Micro-infiltration practices (typically dry wells, French drains or paving blocks) treat runoff from impervious areas of 250 to 2,500 sq. ft.
- Small-scale infiltration practices (typically infiltration trenches or permeable paving) treat runoff from impervious areas of 2,500 to 20,000 sq. ft.
- Conventional infiltration practices (typically infiltration trenches or infiltration basins) treat runoff from impervious areas of 20,000 to 100,000 sq. ft.

Infiltration practices alone are not intended to trap sediment. At locations where sediment might be present, the practices should be designed with a sediment forebay and grass channel or filter strip, or other appropriate pretreatment measures to prevent clogging and failure. In addition, infiltration practices should not be used at sites with significant pollution potential (e.g., stormwater hotspots).

Hydrologic Performance and Targeted Pollutants

Hydrologic Performance

Volume Reduction	Peak Flow Reduction	Groundwater Recharge
●	●	●

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Targeted Pollutants

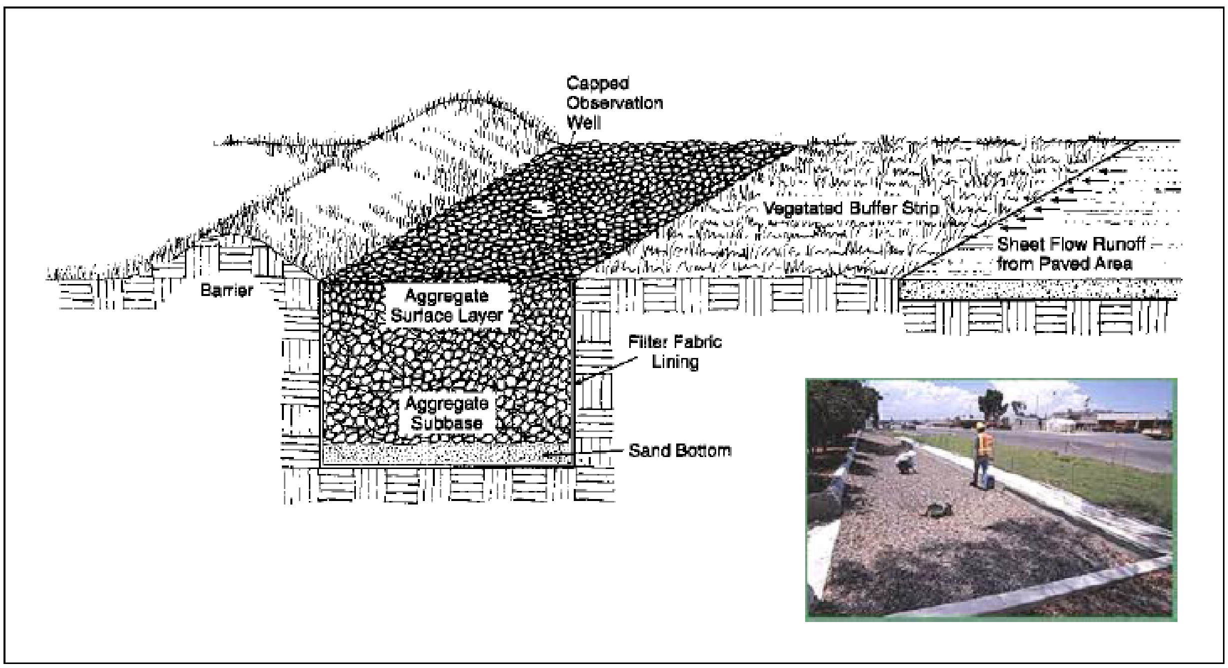
Sediment	Nitrogen	Phosphorus	Metals	Oil & Grease	Bacteria	Temperature
●	⦿	⦿	⦿	○	○	⦿

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Photos and Diagrams

Source: Atlanta Regional Commission 2001

Figure 3A1-12. Infiltration trench.



Source: Atlanta Regional Commission 2001

Figure 3A1-13. Infiltration trench schematic.

Common Feasibility Constraints and Limitations

- Infiltration practices have a high runoff reduction capability and are suitable for use in residential and other urban areas where measured soil permeability rates exceed 0.5 inch per hour (VADCR 2010).

- Infiltration practices provide minimal benefits in terms of reducing concentrations of pollutants such as nitrate because they are below the root zone and surface soil profile.
- Total nitrogen removal is low for many infiltration and filtration practices, with the proportion of nitrate removal extremely low. Designers are using these practices to move water, not remove nutrients. Infiltration trenches can introduce dissolved pollutants such as nitrates and dissolved metals into groundwater (Lucas 2005).
- Infiltration is not recommended at sites designated as stormwater hotspots to prevent possible groundwater contamination. VADCR Design Specification No. 8 (VADCR 2010) provides a table of Potential Stormwater Hotspot and Site Design Responses.
- Excess sediments easily clog infiltration trenches. Hence, infiltration practices should be applied only in situations where pretreatment is provided.
- Sites that have been previously graded or disturbed do not retain their original soil permeability because of compaction; therefore, infiltration practices should not be situated above fill soils.
- Infiltration practices should be designed to minimize potential to create conditions favorable to mosquito breeding, which can occur if they clog and have standing water for extended periods.
- Designers should investigate whether a proposed infiltration practice is subject to a state or local groundwater injection permit.

Runoff Volume and Pollutant Load Removal Estimates

Volume reduction. The amount of volume reduction achieved for infiltration practices can vary based on the size of the infiltration practice and the soil infiltration rate. VADCR (2010) estimates an annual volume reduction from 50 percent (for a typical infiltration practice in soils with an infiltration rate of one-half to one inch/hour) to 90 percent (for an enhanced infiltration practice that is sized 10 percent larger than typical, with additional pretreatment and soils with an infiltration rate of 1.0 to 4.0 inches/hour). This annual volume reduction rate is a function of design and can be increased by modifying the design parameters.

Pitt et al. (2002) also found significant runoff reductions for infiltration practices. For example, sites employing rain gardens (one inch/hour amended soils, 60 sq. ft. per house) achieved annual roof runoff volume reductions of 87 to 100 percent.

Simpson and Weammert (2009) conservatively estimated the volume reduction of infiltration practices to be approximately 80 percent on an annual for the design criteria typically in use at the in Chesapeake Bay region at the time.

Pollutant reduction

Infiltration practices with appropriate pretreatment have been estimated to be able to remove 95 percent of the annual total suspended solids (TSS) load in typical urban post-development runoff when sized, designed, constructed, and maintained appropriately. Undersized or poorly designed infiltration practices can reduce TSS removal performance. Pollutant reduction is a function of the volume removal achieved. A summary of pollutant reduction estimates for infiltration practices in the Chesapeake Bay area is provided in Table 3A1-1.

Practice Design

Several design considerations influence the overall performance of infiltration practices, including

- Areas of Hydrologic Soil Group A or B soils shown on NRCS soil surveys should be considered as primary locations for infiltration practices.
- The contributing drainage area to an individual infiltration practice should be less than 2 acres.
- Infiltration practices should not be hydraulically connected to structure foundations or pavement to avoid harmful seepage. Setbacks to structures and roads vary according to the scale of infiltration. Example specifications (VADCR 2010) state that, at a minimum, and subject to local requirements, conventional and small-scale infiltration practices should be a minimum horizontal distance of 100 feet from any water supply well, 50 feet from septic systems, and at least 5 feet down-gradient from dry or wet utility lines (VADCR 2010).

Brown and Hunt (2009) have identified innovative construction methods that can reduce soil compaction and enhance exfiltration from bioretention cells and permeable pavement. Those construction methods include using a rake method for excavating the bottom of the practice, avoiding excavation during or immediately after a rainfall event, and using boreholes, ripping or trenches to increase exfiltration rates.

Maintenance Considerations and Resources

Maintenance is critical to the success of infiltration practices. The most common maintenance problem is clogging of the stone by organic matter and sediment. The following considerations can minimize the risk of clogging:

- Small-scale and conventional infiltration practices should have an observation port installed at the low point. The observation ports should be inspected regularly and after major storms. A log should be kept of the water level remaining to track changes in the infiltration rate.
- In general, avoid use of geotextile liners because they can be prone to clogging.
- Sediment removal should take place when the basin is thoroughly dry.
- All use of fertilizers, mechanical treatments, pesticides, and other means to assure optimum vegetation health should not compromise the intended purpose of the infiltration basin. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.
- All vegetated areas should be inspected at least annually for unwanted growth, which should be removed with minimum disruption to the remaining vegetation and basin subsoil.
- All structural components should be inspected for cracking, subsidence, spalling, erosion, and deterioration at least annually.

Detailed maintenance considerations are in the *New Jersey Stormwater Best Management Practices Manual* http://www.state.nj.us/dep/stormwater/bmp_manual2.htm) and VADCR Design Specification No. 8 (http://www.chesapeakestormwater.net/all-things-stormwater/infiltration-specification.html).

Costs and Factors Affecting Cost

Infiltration trenches are somewhat expensive, when compared to other stormwater practices, in terms of cost per area treated. Typical construction costs, including contingency and design costs, are about $5 per ft^3 of stormwater treated (SWRPC 1991; Brown and Schueler 1997).

Infiltration trenches typically consume about 2 to 3 percent of the site draining to them, which is relatively small. In addition, infiltration trenches can fit into thin, linear areas. Thus, they can generally fit into relatively unusable portions of a site.

Infiltration basins are relatively cost-effective practices because little infrastructure is needed when constructing them. One study estimated the total construction cost at about $2 per ft^3 (adjusted for inflation) of storage for a 0.25-acre basin (SWRPC 1991). Infiltration basins typically consume about 2 to 3 percent of the site draining to them, which is relatively small. Maintenance costs are estimated at 5 to 10 percent of construction costs.

Costs reported for infiltration practices in a 189-acre watershed included costs for infiltration trenches, and infiltration vault, raingardens, and a regional pond (CRWD 2010). The project included eight infiltration trenches, serving 16 acres of drainage area with a total storage volume of 19,354 ft^3. Averaged costs reported were $7.69/$ft^3$ for design and construction, not including bond interest; the construction cost component was $6.41/$ft^3$.

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1.7 Soil Restoration

Description of Practice

Soil restoration techniques can be used to improve compacted soils. The addition of compost can increase soil organic content, provide beneficial bacteria and fungi, and improve or restore soil water retention capacity and overall soil permeability. The addition of soil amendments can delay and often reduce the peak stormwater run-off flow rate and volume and decrease irrigation water requirements. Amending soils will also reduce fertilizer and pesticide requirements. Soil restoration techniques can also be used as part of a system to provide additional retention or infiltration capacity to manage runoff from disconnected gutters, grass channels, filter strips, and impervious areas.

Compost amended soils are suitable for any pervious area where soils have been or will be compacted by the grading and construction process. Compost amendments can be applied to the entire pervious area of a development or be targeted in select areas of the site to enhance the performance of runoff reduction practices. Some common design applications include

- Reduce runoff from compacted lawns and bare soils
- Increase volume of runoff infiltrated from rooftops or other areas
- Increase volume of runoff infiltrated within a grass channel or filter strip
- Increase volume of runoff reduced by a tree cluster or reforested area of the site (VADCR 2009)

Hydrologic Performance and Targeted Pollutants

The primary water quality improvements that result from restoring soil through tillage and compost amendments are increased infiltration and the resulting reduction in runoff volumes. Reducing runoff volume with compost generally reduces pollutant transport and loading off-site (Faucette et al. 2005, 2007).

Photos and Diagrams

Source: VADCR Specification No. 4

Figure 3A1-14. Soil amendments.

Common Feasibility Constraints and Limitations

Compost amendments are not recommended where

- Existing soils have high infiltration rates (e.g., HSG A and B soils), although compost amendments might be needed at mass-graded B soils to maintain runoff reduction rates
- The water table or bedrock is within 1.5 feet of the soil surface
- Slopes exceed 10 percent, unless surface applied as a compost blanket
- Existing soils are saturated or seasonally wet
- The use of tillage with soil amendments would harm roots of existing trees (stay outside the tree drip line)
- The downhill slope runs toward an existing or proposed building foundation
- The contributing impervious surface area exceeds the surface area of the amended soils (VADCR 2009)

Selecting the compost amendments should occur on the basis of the water quality objectives of the jurisdiction or the project. Compost amendments should be formulated to not adversely affect water quality. Properties such as nutrient content, soil moisture holding capacity, metals uptake capacity, shrink/swell, product maturity, pathogen, residual chemical content and weed seed content require a high level of scrutiny to ensure that the appropriate amendments are being used (Lenhart 2007).

Runoff Volume and Pollutant Load Removal Estimates

Balousek (2003) conducted research that demonstrated that compost-amended, chisel-plowed, and deep-tilled plot treatments showed runoff reductions from 74 to 91 percent, compared to the control. Chisel-plowed and deep-tilled treatment showed cumulative runoff reductions of 40 to 53 percent, compared to the control (Balousek 2003). The runoff reduction volume achieved by soil restoration depends on the site application and the pre-construction hydrologic soil group (VADCR 2009).

The use of compost amendments can reduce or eliminate the need for supplemental fertilization from inorganic fertilizer sources. Some studies, however, show that the concentrations of many pollutants can increase in the surface runoff after soils are amended with compost, hence the need for specification standards where nutrient runoff is to be limited. A study conducted by EPA's Office of Research and Development (Pitt et al. 1999) found that surface runoff from the compost-amended soils had greater concentrations of almost all constituents, compared to the surface runoff from the control sites. The concentration increases in the surface runoff and subsurface flows from the compost-amended soil test site were quite large, typically in the range of 5 to 10 times greater. Subsurface flow concentration increases for the compost-amended soil test sites were also common and about as large. When the decreased surface flow quantities were considered in conjunction with the increased surface runoff concentrations, it was found that all the surface runoff mass discharges were reduced by large amounts (to 2 to 50 percent of the unamended discharges). The large phosphorus and nitrogen compound concentrations found in surface runoff and subsurface flows at the compost-amended soil sites decreased significantly during the time of the tests (about 6 months). The older test sites also had lower nutrient concentrations than the new sites but still had elevated concentrations when compared to the soil-only test plots.

Use of compost and soil amendments with quality control specifications will help avoid potential issues such as excess nutrient runoff. Use of compost-amended soils can result in an overall nutrient loading increase, at least initially, so the trade-off between volume reduction enhancement and potential nutrient concentration increase should be considered.

The quality of compost being used (i.e., feed stock, maturity, presence of pesticides and herbicides) must be considered to minimize the adverse effects of water quality. One recent study concluded that because of its high nutrient content, but low leaching properties, mature compost made from deciduous leaves makes suitable compost for soil amendment in applications for water quality (Lenhart 2007). Two studies conducted at the University of Georgia found that when quality compost was used and compared to conventional seeding and mulching applications, runoff nitrogen loading was reduced by 58–92 percent, and runoff phosphorus loading was reduced by 83–97 percent (Faucette et al. 2005, 2007).

Practice Design

- The depth of compost amendment is based on the relationship between the surface area of the soil amendment to the contributing area of impervious cover that it receives. VADCR Stormwater Design Specification No. 4 (www.chesapeakestormwater.net/all-things-stormwater/soil-compost-amendments.html) includes a table (Table 3) that provides guidance as to the depth of compost, incorporation depth, and incorporation type based on the area to be amended and the contributing impervious area.

- EPA's Compost Blanket Factsheet includes guidelines and specifications for compost blankets for construction and post-construction use. (http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=118).

- The compost material should be well composted, free of viable weed seeds, and stable with regard to oxygen consumption and carbon dioxide generation. The compost should have a moisture content that has no visible free water or dust produced when handling the material. VADCR Stormwater Design Specification No. 4 (www.chesapeakestormwater.net/all-things-stormwater/soil-compost-amendments.html) and the Low Impact Development Center (www.lowimpactdevelopment.org/epa03/saspec_print.htm) provide technical specifications for the compost material.

- Soil tests should be conducted during two stages of the compost-amendment process. The first testing is done to ascertain pre-construction soil properties at proposed amendment areas. The second soil analysis is taken to determine whether any further nutritional requirements, pH, and organic matter adjustments are necessary for plant growth.

- VADCR Stormwater Design Specification No. 4 (www.chesapeakestormwater.net/all-things-stormwater/soil-compost-amendments.html) includes design criteria for soil amendments used to enhance downspout disconnections, grass channels, vegetated filter strips, in addition to several Bay-specific regional design variations.

- The City of Redmond, Washington Guidelines for Landscaping with Compost-Amended Soils (www.redmond.gov/insidecityhall/publicworks/environment/pdfs/compostamendedsoils.pdf) (Chollak and Rosenfeld 1998) provides design specifications and cost-benefit analysis of using compost-amended soils.

- The Composting Council and the Clean Washington Council developed guidance (Development of a Landscape Architect Specification for Compost Utilization, www.cwc.org/organics/org972rpt.pdf), which contains a series of short and long compost use specifications for various landscape applications. Both product specifications and end-use instructions are provided.

Maintenance Considerations and Resources

VADCR (2009) recommends that specific practices be used during the first year after amendment to help ensure success where turf is the appropriate groundcover. Establishing other landscape cover types, such as forest cover or native plantings, could require fewer or no follow-up chemical inputs after the site has been stabilized. VADCR recommendations for turf are

- Initial inspections: For the first 6 months following amendments, the site should be inspected at least once after each storm event that exceeds one-half inch.

- Spot Reseeding: Inspectors should look for bare or eroding areas in the contributing drainage area or around the soil restoration area, and make sure they are immediately stabilized with grass cover.

- Fertilization: Depending on the amended soils test, a one-time, spot fertilization might be needed in the fall after the first growing season to increase plant vigor.
- Watering: Water once every 3 days for first month, and then weekly during first year (Apr–Oct), depending on rainfall (VADCR 2009).

Item	Unit	Estimated unit cost (2005 dollars)
Soil and site preparation	S.Y.	\$5–\$8
Mechanical grading and tilling	S.Y.	\$18–\$27
Soil amendments	C.Y.	\$15–\$30
Blower application	S.Y.	\$0.45–\$1.00

Costs and Factors Affecting Cost

Costs include the amendment and the application into the existing soil. Typical costs are provided below (http://www.lowimpactdevelopment.org/ffxcty/5-1_soilamendments_draft.pdf).

Item	Unit	Estimated unit cost (2005 dollars)
Soil and site preparation	S.Y.	\$5–\$8
Mechanical grading and tilling	S.Y.	\$18–\$27
Soil amendments	C.Y.	\$15–\$30
Blower application	S.Y.	\$0.45–\$1.00

Cost calculations based on amending soils on one-quarter acre area to manage runoff for a one-half acre area were prepared by the Low Impact Development Center for Fairfax County, Virginia, in 2005, as follows:

Item	Required cost per year (2005 dollars)											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**…**	**25**
Installation	25,000												
Aerate			250		250		250		250		250		
Re-amend													25,000
Total cost	**25,000**		**250**		**250**		**250**		**250**		**250**		**25,000**
Annualized Cost	\$1,125/year (includes re-amending in year 25)												

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1.8 Reforestation and Urban Forestry

Description of Practice

Forests are the most beneficial land use to protect the water quality of the Chesapeake Bay (USDA Forest Service*, Urban Tree Canopy Goal Setting*, 2006). Reforestation is the protection, enhancement and expansion of tree canopy in urban and suburban areas, in yards, parks, along streets, and public places. Urban forests provide significant environmental benefits through management of urban stormwater but also provide other benefits such as increasing property values, reducing energy costs for cooling in the summer, buffering wind and noise, improving air quality, providing habitat for wildlife, and beautifying the landscape. In urban areas, trees provide an important stormwater management function by intercepting rainfall that would otherwise run off of paved surfaces and be transported into local waters through the storm drainage system, picking up various pollutants along the way (CWP and USFS 2009). Trees also enhance stormwater management by evapotranspiring large quantities of stormwater, while the roots help to reduce soil compaction, enabling more infiltration of stormwater. In general, trees stabilize soils, reduce stormwater runoff, maintain the base flow of streams and filter nutrients and sediment (CWP 2007).

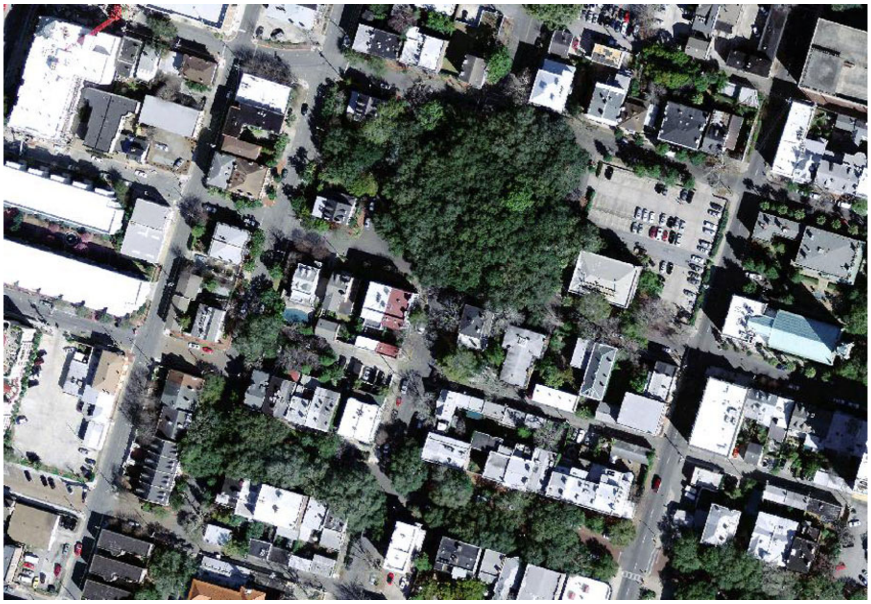
Reforestation can be achieved using many tools, such as developing an urban tree canopy goal for a site or community, and achieving that goal through the use of regulations, policies and/or incentives to plant trees and help ensure continued growth (Table 3A1-8).

Table 3A1-8. Urban watershed forestry objectives, by goal

Goal	Objective	Description
1. Protect	A. Protect priority forests	Select large tracts of currently unprotected and undeveloped forest to protect from futures development.
	B. Prevent forest loss during development and redevelopment	Directly or indirectly reduce forest clearing during construction
	C. Maintain existing forest canopy	Prevent clearing and encroachment on existing protected and unprotected forest fragments on developed land.
2. Enhance	D. Enhance forest fragments	Improve the structure and function of existing protected forests.
3. Reforest	E. Plant trees during development and redevelopment	Require on-site reforestation as a condition of development.
	F. Reforest public land	Systematically reforest feasible planting sites within public land, rights-of-way, or other priority sites.
	G. Reforest private land	Encourage tree planting on feasible locations within individual yards or property

Source: Cappiella et al. 2005. *Urban Watershed Forestry Manual. Part 1: Methods for Increasing Forest Cover in a Watershed,* USDA Forest Service, Newtown Square, PA.

Photos and Diagrams



Source: CWP and USDA 2009

Figure 3A1-15. Urban tree canopy.

Common Feasibility Constraints and Limitations

- Developers have little incentive to leave or restore trees on development projects.
- Unless regulations or incentives are in place, property owners might not protect existing or plant additional trees.
- Utility corridor management needs lead to tree losses and damage.
- Human safety (fire response and transportation projects) often require tree removal.

Runoff Volume and Pollutant Load Removal Estimates

On average, forests contribute approximately one-tenth of the nitrogen to the Chesapeake Bay compared to developed lands (1.7 lbs acre compared to 14.8 lbs/acre). More specifically, riparian forests that buffer streams significantly reduce the amount of excess nutrients that enter the water, sometimes by as much as 30 to 90 percent (CBP 2007).

Forested areas have less runoff than developed areas, as indicated by the smaller runoff coefficient used when comparing to disturbed or impervious areas (Table 3A1-9).

Table 3A1-9: Site cover runoff coefficients[a]

Soil condition	Runoff coefficient
Forest Cover	0.02–0.05[b,c]
Disturbed Soils/Managed Turf	0.15–0.25[b,d]
Impervious Cover	0.95

Source: Hirschman et al. 2008

[a] Derived from research by Pitt et al. 2005; Lichter and Lindsey 1994; Schueler 2001a, 2001b; Legg et al. 1996; Pitt et al. 1999; Schueler 1987; and Cappiella et al. 2005.

[b] Range dependent on original Hydrologic Soil Group (HSG)

[c] Forest - A: 0.02 B: 0.03 C: 0.04 D: 0.05

[d] Disturbed Soils - A: 0.15 B: 0.20 C: 0.22 D: 0.25

Research has shown that trees are the most effective at reducing the runoff from small, more frequent storms (CWP and USDA 2009). Volume removal credit for trees has been adopted in stormwater programs, for example Washington State Department of Ecology has acknowledged one type of tree box structure (one that reduces soil compaction from load-bearing pavements by using a structural *vault*) as functionally equivalent to a rain garden. Allowing credit for the site-specific annual evapotranspiration should be considered, and research is being done, primarily by the U.S. Forest Service, to help make the tools available.

Practice Design

Many local, regional, and site-specific practices can be implemented to conserve existing urban forest and increase forest restoration. Local and state governments, and federal facilities, can develop policies operating procedures, contract specifications, or planning documents that incorporate urban forestry. They can encourage/require practices such as stream buffers and provide incentives for developers and property owners to conserve or restore urban forests. The following resources provide more information about those options:

- Guidelines for Developing and Evaluating Tree Ordinances (International Society of Arboriculture) - www.isa-arbor.com/publications/ordinance.aspx
- Protecting Water Resources with Higher Density Development (USEPA) www.epa.gov/dced/pdf/protect_water_higher_density.pdf
- Forest Friendly Development (Alliance for the Chesapeake Bay) www.alliancechesbay.org/pubs/projects/deliverables-145-8-2005.pdf

In addition, local governments lead by example and invest in urban forestry. Federal facilities can look to those programs for ideas on program implementation and for evidence of how trees are valued by the community at large, both for stormwater management benefits and other amenity value. For example, the Philadelphia Water Department Office of Watersheds (see www.phillyriverinfo.org/Programs/SubprogramMain.aspx?Id=TreeVitalize) contends that “trees are one of the most effective, least costly methods of storing and controlling stormwater runoff.” The Office of Watersheds has already contributed to planting more than 500 trees in Philadelphia and hopes to increase this number through its involvement with the regional TreeVitalize Program (see www.treevitalize.net). As part of this program, Office of Watersheds will partner with the Fairmount Park

Commission to receive $300,000 over a 3-year period to plant up to 84 acres of forested riparian buffers throughout Philadelphia's park system (PWD 2009).

Federal Implementation of the Chesapeake Executive Council Directive on Forest Conservation provides specific actions to help achieve the goals of urban forest conservation and restorations. (www.chesapeakebay.net/press_ec2007forests.aspx?menuitem=20276)

- An example of local leadership in reforestation is Baltimore County's *Growing Home* Campaign. Benefit information is provided, including links to American Forests Personal Climate Change Calculator, and the National Tree Benefits calculator from Casey Trees, a local nonprofit. The tools help to educate the public on the multiple benefits of trees. The county provides financial incentives to plant trees through a public-private partnership with local nurseries and tree retailers.

The Center for Watershed Protection (www.cwp.org) and the USDA Forest Service have developed new designs for stormwater management practices for use in incorporating functional tree-based stormwater management systems into developments. The *stormwater forestry practices* address potential limitations through design modifications, species selection, and other methods. The designs listed below harness the benefits of trees to increase the effectiveness of stormwater practices, while providing other benefits to the community, such as cooling and shade, aesthetics, and wildlife habitat (CWP and USDA 2009). The fact sheets listed below are at www.forestsforwatersheds.org/reduce-stormwater.

- Wooded wetland
- Emergent pond/wetland system
- Bioretention and bioinfiltration facilities
- Alternating side slope plantings
- Tree check dams
- Forested filter strip
- Multi-zone filter strip
- Linear stormwater tree pit
- Stormwater treatment dry ponds

Trees design in dense urban environments presents many challenges with the infrastructure of streets, sidewalks, and utilities. Resources for addressing these issues include *Reducing Infrastructure Damage by Tree Roots: A Compendium of Strategies* (Costello and Jones 2003). Other planning considerations such as neighborhood character in tree selection and placement are essential for a successful community street tree program (*The Road to a Thoughtful Street Tree Master Plan: A Practical Guide to Systematic Planning and Design,* Simons and Johnson 2008*).*

Practices to prevent root compaction and provide additional space under pavements for tree root growth are gaining acceptance. One example is Minnesota's MARQ2 project that used an elevated-pavement type structural support system for the planting of 179 trees along a redeveloped streetscape in the downtown area. The system was designed to manage stormwater as one of its functions to help prevent combined sewer overflows (http://www.stormh2o.com/march-april-2010/reshaping-minneapolis-project.aspx).

More information on using trees to manage stormwater is at

- Urban Watershed Forestry Manual Part 2: Conserving and Planting Trees at Development Sites www.forestsforwatersheds.org/storage/part2forestrymanual.pdf
- Stormwater Management: Using Trees and Structural Soils to Improve Water Quality www.cnr.vt.edu/urbanforestry/stormwater
- Watershed Forestry Resource Guide—Reducing Stormwater Runoff www.forestsforwatersheds.org/reduce-stormwater

Maintenance Considerations and Resources

The benefits of urban trees can be extended with appropriate selection, planting design, and maintenance. American Forests estimates that the average life expectancy of a downtown urban street tree is just 13 years, while their rural counterparts can live up to 100 years or more. Symptoms of tree decline from urban stressors can take years to appear. Common causes of urban tree mortality include the following:

- Damage to roots or soils from nearby construction activities
- Air pollution
- Physical damage from lawnmowers, vehicles, or vandals
- Damage from disease and insects
- Trees planted in too small a space
- Improper planting and pruning techniques
- Tree stakes or grates left on too long
- Poor, compacted soils
- Lack of watering
- Removal or damage during maintenance of nearby utilities or sidewalks
- Competition from invasive plant species (CWP and USDA 2009)

The Urban Watershed Forestry Manual Part 3: Urban Tree Planting Guide (CWP 2006) (at www.forestsforwatersheds.org/storage/Part3ForestryManual.pdf) provides detailed guidance on urban tree planting, including site assessment, planting design, site preparation, and planting and maintenance techniques.

Costs and Factors Affecting Cost

The costs of reforestation will vary greatly by how and where the trees are incorporated into the urban/suburban landscape. A recent source of information on program cost is the American Public Works Association urban forestry handbook. This project was supported by the USDA Forest Service Urban and Community Forestry Program on the recommendation of the National Urban and Community

Forestry Advisory Council. The handbook series is titled *Urban Forestry Best Management Practices for Public Works Managers,* and the individual handbooks are the following:

- Volume 1 *Budgeting and Funding*
- Volume 2 *Staffing*
- Volume 3 *Ordinances, Regulations, & Public Policies*
- Volume 4 *Urban Forest Management Plan*

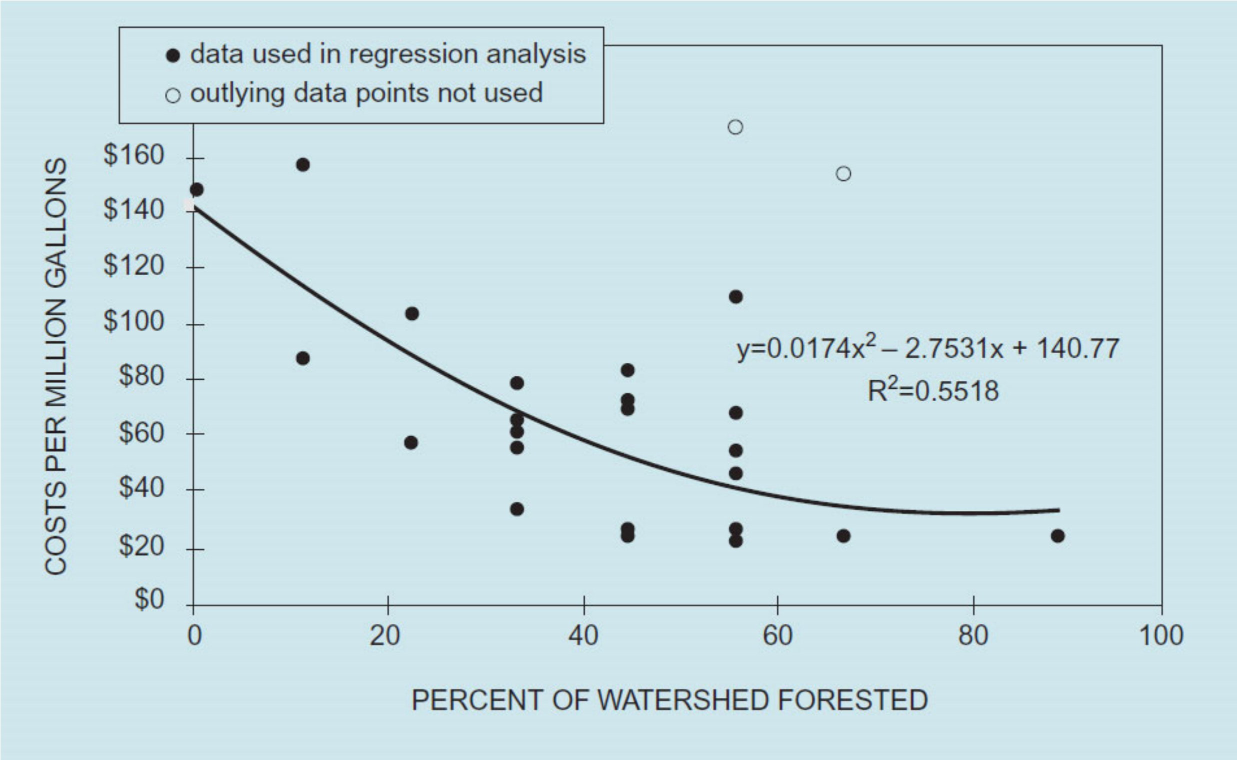
The series is available free for download at APWA Press, www.apwa.net/About/CoopAgreements/urbanforestry.

The value of the economic benefits of planting trees will also vary, however, and research is being done to attempt to quantify the value of urban tree canopy. American Forests (www.americanforests.org) has developed a tool to calculate the value of urban tree canopy in metropolitan areas, called CITYGreen. For example, American Forests determined that 34 percent of Montgomery, Alabama, was covered by tree canopy in 2002. The stormwater-retention capacity of Montgomery's urban forest is 227 million ft^3. The cost to manage that volume of runoff in traditional infrastructure is estimated at $454 million. In addition, Montgomery's urban forest is estimated to remove 3.2 million pounds of pollutants from the air annually, and that benefit is valued at $7.9 million (American Forests 2004). Even in arid locations, trees are important. In 2007 American Forests found that Albuquerque, New Mexico's tree canopy provided 20 million cubic feet in stormwater detention services, valued at $123 million (American Forests 2009).

Further, forests filter pollutants from runoff, therefore, allowing fewer contaminants to reach potable water sources. That results in less treatment costs for local governments.

An example of that is in a 2002 study by the Trust for Public Land and the American Water Works Association. For every 10 percent increase in forest cover in the source watersheds evaluated in the survey, treatment costs decreased by approximately 20 percent, up to about 60 percent forest cover (see Figure 3A1-16). No conclusion could be made for watersheds with more than 60 percent cover because of a lack of data. Treatment costs can level off when forest cover is between 70 and 100 percent, the study estimated. Other factors affecting treatment costs include the treatment practices used, the size of the facility, and the land use characteristics, including use of BMPs (*Watershed Forestry Guide,* Center for Watershed Protection and U.S. Forest Service. (www.forestsforwatersheds.org/forests-and-drinking-water/).

The USDA Forest Service provides a Guide for Chesapeake Bay Communities (see www.jmorgangrove.net/Morgan/UTC-FOS_files/UTC_Guide_Final_DRAFT.pdf) to assist them with the setting and evaluation of urban tree canopy goals. Setting tree canopy goals is essential to achieving program success. Principles of an effective urban forest program and several case studies across the United States are provided in the U.S. Forest Service-supported guide *Planning the Urban Forest: Ecology, Economy, and Community Development* (Schwab 2009).



Source: www.forestsforwatersheds.org/forests-and-drinking-water/

Figure 3A1-16. Relationship between forest cover and water treatment costs. Practice/program evaluation

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1.9 Street Sweeping

Description of Practice

Street sweeping is not a GI/LID practice, and reliance on this practice unfortunately requires repeating the investment continually. However, the current design and operational practices for roadways do present a need for street sweeping for water quality and for safety and aesthetics. This fact sheet is included to provide new information on street sweeping practices.

Street sweeping can provide significant pollutant removal, but many municipalities use sweepers that do not perform effectively or that can actually cause more water quality issues (Pitt et al. 2004). Aesthetics is the main reason most municipalities use sweepers, not water quality. For that use, *mechanical* broom sweepers can perform well. However, they do not provide the level of water quality benefit that can be obtained using improved sweepers.

Streets and roads compose up to 20 percent of total impervious cover in suburban subwatersheds and up to 40 percent in highly urban subwatersheds. Contaminated particulates or *street dirt* accumulates along curbed roads between rainfall events. During intense rainfall events, additional particulates can be washed on to these paved surfaces from adjoining land areas. This wet weather wash-on has been demonstrated to be quite important in understanding the pollutant removal benefits of street sweeping (Sutherland and Jelen 1996). Sources of pollutants include wash-on, atmospheric deposition, vehicle emissions, cargo spills, and wear and tear, breakup of street surface, road salts and deicers, litter, bird droppings, grass clippings, leaves and other organic material and sanding. That results in the accumulation of stormwater pollutants such as sediment, nutrients, metals, hydrocarbons, bacteria, pesticides, trash, and other toxic chemicals (CWP 2008).

Pollutants typically remain on streets until they are washed into the storm drain system during a rainfall event. However, some communities use street sweeping to remove some of the pollutants and prevent them from being conveyed into the storm drain system (CWP 2008).

Street sweeping and vacuuming includes the use of self-propelled and walk-behind equipment to remove sediment from streets and roadways and to clean paved surfaces in preparation for final paving. Sweeping and vacuuming prevents sediment from entering storm drains or receiving waters (CASQA 2003).

Targeted Pollutants (Highly Dependent on Equipment Type)

Targeted Pollutants

Sediment	Hydrocarbons	Trash	Nutrients
⦿	⦿	⦿	⦿

Key: ● High effectiveness ⦿ Medium effectiveness ○Low effectiveness

Photos and Diagrams

Source: www.quincyma.gov/Living

Figure 3A1-17. The majority of pollutants on streets is closest to the curb.

Common Feasibility Constraints and Limitations

The following are common feasibility constraints and limitations of street sweeping:

- Sweeping and vacuuming might not be effective when sediment is wet or when tracked soil is caked (caked soil might need to be scraped loose) (CASQA 2003).
- Be careful not to sweep up any unknown substances or any object that could be hazardous (CASQA 2003).
- The use of kick brooms or some sweeper attachments tend to spread dirt rather than remove it (CASQA 2003). On the other hand, gutter brooms can be very effective at capturing street dirt.
- Access to the curb is paramount to street sweeping efficiency because the majority of pollutants on streets is closest to the curb. Parked cars can restrict access. Compliance with an appropriately enforced no-parking zone can provide access for street sweeping to the curb (CWP 2008).

Pollutant Load Removal Estimates

The ability of street sweepers to remove common stormwater pollutants varies depending on the sweeper technology being used, climate factors such as rainfall patterns, sweeper operation (including sweeper speed), sweeper maintenance (including broom wear), sweeping frequency, pavement conditions, the number of parked cars encountered, and the chemical and physical characteristics of the pollutants that have accumulated on the pavement. In addition, it can be difficult to estimate pollutant removal rates for street sweepers because of the difficulty in measuring particulate matter transported in runoff (APWA 2009).

Pros and cons of sweeper type on pollutant removal performance consist of the following:

- Mechanical street sweepers are more effective at removing larger-sized particles than fine-grained particles and nutrients. Newer high-efficiency sweepers pick up much smaller particles (Sutherland and Jelen 1997; Pitt et al. 2004).
- Mechanical sweepers are typically the least expensive and are better suited to pick up trash and coarse-grained sediment particles (CWP 2008). They provide less water quality benefits, but they

could be used as the first pass of tandem sweeping operations when followed by a sweeper that can remove the pollutant-heavy, fine-sized particles left behind by the mechanical sweeper.

- Regenerative-air and high-efficiency sweepers are better at removing fine-grained sediment particles but are less effective on wet surfaces (although they can still outperform mechanical sweepers) and are more expensive (CWP 2008).
- Street sweeping is presumed to be more effective at reducing stormwater pollutants in arid and semi-arid climates where pollutants can accumulate over longer intervals on street and curb surfaces (CWP 2008).

Practice Design

- Because they operate as a mobile BMP on-the-go, street sweeping can be of particular value in reducing pollutants from ultra-urban areas where few BMPs are feasible (Law et al. 2008).
- Street cleaning equipment can be most effective in areas where the surface to be cleaned is the major source of contaminants. Such areas include freeways, large commercial parking lots, and paved storage areas (Pitt et al. 2004).
- Improving or initiating street sweeping activities can reduce the amount of stormwater pollution that is conveyed into local aquatic resources. It requires examination of existing street sweeping technology and operations (if any) and identification of where improvements can be made to reduce the amount of pollution that has accumulated on public streets and roadways. (CWP 2008).
- Develop a list of areas where street sweeping activities could have the greatest influence on water quality. For example, an area with high accumulations of pollutants might suggest that more regularly scheduled street sweeping is needed. Also, street sweeping can be concentrated on the dirtiest streets in sensitive subwatersheds (CWP 2008).
- At a minimum, sweeping should occur during periods of heavy accumulation, such as early spring removal of deicing chemicals and sand in temperate climates (CWP 2008). During the fall, leaf removal should be conducted with specialized equipment, such as vactor trucks, because seasonal leaves can contribute 25 percent of nutrient loading in catch basins.
- Include municipal parking lots in the sweeping schedule.

Costs and Factors Affecting Cost

Several factors influence the overall cost of street sweeping:

- Street sweeping is major investment, and operators must be specially trained on how to properly drive and maintain them. Training should be held at least once a year for staff to provide them with a thorough understanding of the proper implementation of sweeping and other pollution prevention/good housekeeping practices and safety procedures (CWP 2008).
- Costs can vary significantly by the type of sweeper, operation and maintenance expenses, and sweeping frequency. The capital cost for a conventional street sweeper is between $60,000 and $120,000, with newer technologies approaching $180,000 (CASQA 2003).

Practice/Program Evaluation

It is important to evaluate the process and measurable performance goals and implementation milestones made for a street sweeping program (Table 3A1-10).

Table 3A1-10. Examples of measurable goals and implementation milestones for improving municipal street sweeping activities[a]

Example measurable goals	Time frame	Priority
Goals related to program startup		
Identify and collect basic information about municipal street sweeping activities	Complete shortly after program startup; updated regularly after that	Essential
Add the information about street sweeping activities to the simple database or binder that contains basic information about each municipal operation		Essential
Develop a digital GIS or hard copy map showing the location of all municipal street sweeping activities		Optional but recommended
Prioritize local pollution prevention/good housekeeping efforts	Year 1, repeat every 5 years	Essential
Goals related to preventing or reducing stormwater pollution		
Collect additional information about the way that street sweeping activities are conducted within your community. Include sweeper type; efficiency of fine sediment fraction removed, sweeping frequency, miles swept/coverage, and parking policies and enforcement along sweeping routes.	Year 1	Essential
Prescribe pollution prevention/good housekeeping practices to improve the way that municipal street sweeping activities are conducted within your community		Essential
Develop implementation plan for prescribed street sweeping program		Essential
Secure funding and resources to implement prescribed street sweeping program	Begin in Year 1	Essential
Implement prescribed street sweeping program	Begin in Year 2	Essential
Goals related to program evaluation		
Develop measurable performance goals and implementation milestones	Complete shortly after program startup; updated regularly after that	Essential
Evaluate progress in meeting measurable goals and implementation milestones, including pollution prevent/good housekeeping practices		Essential

Source: adapted from CWP 2008
a. These goals assume that street sweeping is at the top of your prioritized municipal operations list.

The methods used to evaluate success in meeting measurable goals and implementation milestones can be as simple as a semi-annual or annual inspections used to identify the improvements that have been put in place and the improvements that still need to be made (CWP 2008).

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1.10 Constructed Wetlands

Description of Practice

Wetland systems are designed for flood control and removal of pollutants from stormwater. Like natural wetlands, stormwater wetlands (a.k.a. constructed wetlands) temporarily store the water and have the capacity to improve water quality through microbial breakdown of pollutants, plant uptake, retention of stormwater, settling and adsorption (Barr 2001). Constructed wetlands, like wet ponds, incorporate wetland plants into the design and require relatively large contributing drainage areas. As stormwater runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake. Constructed wetlands have zones and plants similar to wet ponds but often with less fluctuation and the ability to maintain a higher diversity (Shaw 2003).

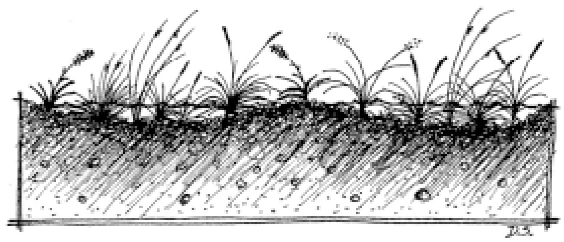
Wetlands are among the most effective stormwater practices in terms of pollutant removal and also offer aesthetic and habitat value. Although natural wetlands can sometimes be used to treat stormwater runoff that has been properly pretreated, stormwater wetlands are fundamentally different from natural wetland systems. Constructed wetlands are designed specifically for treating stormwater runoff, and typically have less biodiversity than natural wetlands in terms of both plant and animal life. Several design variations of the constructed wetland exist, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland. Sediment forebays and micropools are often designed as part of constructed wetlands to prevent sediment from filling the wetland (Barr 2001).

A distinction should be made between using a constructed wetland for stormwater management and diverting stormwater into a natural wetland. The latter practice is not recommended because altering the hydrology of the existing wetland with additional stormwater can degrade the resource and result in plant die-off and the destruction of wildlife habitat. In all circumstances, natural wetlands should be protected from the adverse effects of development, including impacts from increased stormwater runoff. This is especially important because natural wetlands provide stormwater and flood control benefits on a regional scale (USEPA 2006).

Photos and Diagrams

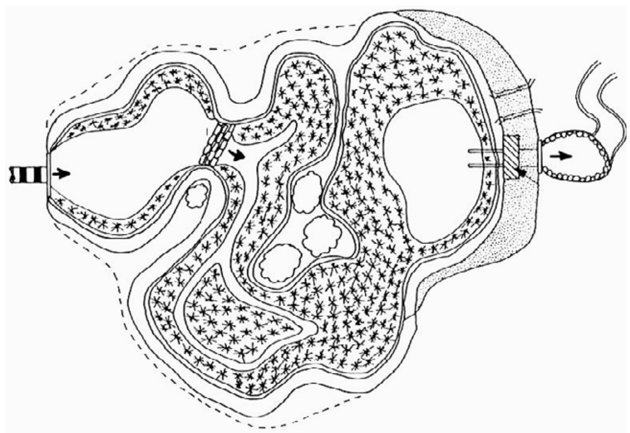
Source: USEPA 2006

Figure 3A1-18. Stormwater wetland.



Source: Shaw 2003

Figure 3A1-19. Drawing of a wetland.



Source: Barr 2001/Schueller 1992

Figure 3A1-20. Plan diagram of a shallow marsh constructed wetland.

Photo by A.H. Baldwin. Source: Simpson 2009

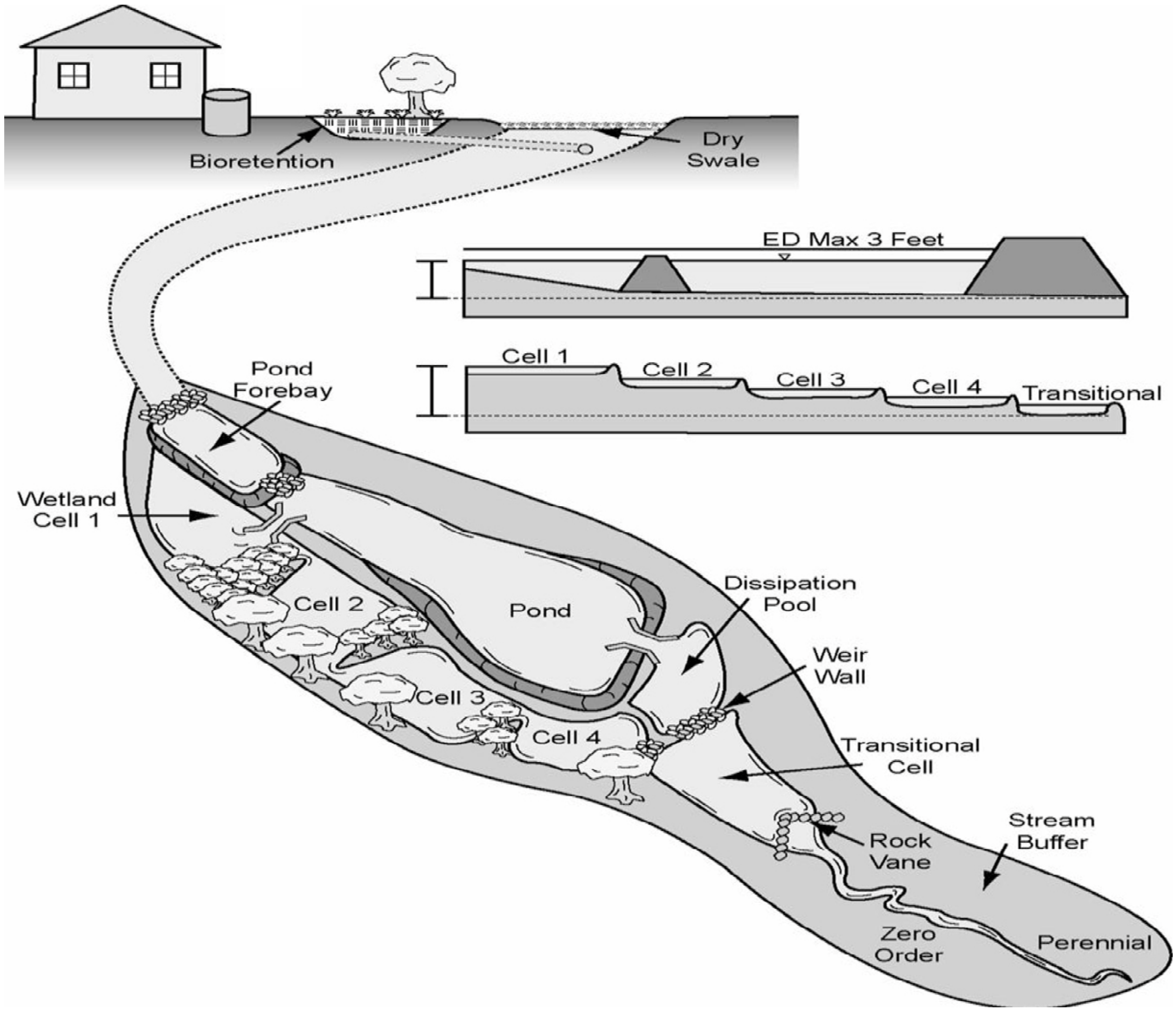
Figure 3A1-21. Stormwater wetland at the University of Maryland, College Park. Runoff from the parking lot enters the wetland from the left, flows in a roughly U-shaped counterclockwise pattern, and discharges via a riser at the top center of the wetland.

Source: VA DCR 2009

Figure 3A1-22. A constructed wetland basin.

Source: VA DCR 2009

Figure 3A1-23. Plan view constructed wetland basin.



Source: VA DCR 2009

Figure 3A1-24. Pond/wetland combination.

Common Feasibility Constraints and Limitations

Constructed wetlands are widely applicable and can be applied in most regions of the United States; however, there are limitations in specific climates and areas, including

- Arid and semi-arid climates where evaporation makes it difficult to retain water in a shallow pool
- Ultra-urban areas with little pervious surface available for the large land area required
- *Hot spots* that have a high potential for groundwater contamination, e.g., gas station runoff or areas where chemicals are stored or managed
- Retrofit or new construction in areas with minimal land

- Cold water trout streams because of thermal effects of heating a shallow pool, which can discharge warmer water
- Breeding ground for mosquitoes in improperly designed systems
- Careful selection of plants that will sustain life over the lifetime of the project
- Nutrient release can occur during the non-growing season
- Consideration of impact on natural wetlands and forests

(Adapted from USEPA 2006)

Pollutant reduction. Considerable variations exist in both methods of reporting treatment effectiveness, and a broad range of effectiveness is noted for individual sites. In a literature review conducted for these practices in the Chesapeake Bay region, effectiveness estimates for urban constructed wetlands were 60 percent for total suspended solids, 20 percent for total nitrogen and 45 percent for total phosphorus, and volume reduction was not noted as significant source of pollutant removal (Simpson et al. 2009). One study found that an experimental system had little potential for long-term, consistent mass removal of total nitrogen and total phosphorus, depending on the concentrations in the incoming runoff (Nietch et al. 2005).

Results from the studies show that some bacteria removal and inactivation can occur in constructed wetlands. The factors of light, time, temperature, and other factors (e.g., predation, sedimentation, sorption, filtration, pH, BOD, and DO) can also contribute to the inactivation of indicator bacteria in constructed wetland BMPs (USEPA 2006).

Cold weather performance. Cold temperatures can cause freezing of the permanent pool or freezing at inlets and outlets. Also in the winter, high salt concentrations in runoff from road salting, and high sediment loads from road sanding, can affect wetland vegetation. During the spring, snowmelt can carry a relatively high pollutant load with the high volume of runoff.

One of the greatest challenges of stormwater wetlands, particularly shallow marshes, is that much of the practice is very shallow. Therefore, much of the volume in the wetland can be lost as the surface of the practice freezes. One study found that the performance of a wetland system was diminished during the spring snowmelt because the outlet and surface of the wetland had frozen. Sediment and pollutants in snowmelt and rainfall events *skated* over the surface of the wetland, depositing at the outlet of the wetland. When the ice melted, this sediment was washed away by storm events (Oberts 1994). Several design features can help minimize this problem, including the following:

- *On-line* designs allowing flow to move continuously can help prevent outlets from freezing.
- Multiple cells, with a berm or weir separating each cell, can help retain storage for treatment above the ice layer during the winter season.
- Freeze-resistant outlets (i.e., weirs or pipes with large diameters).
- Planting salt-tolerant vegetation, such as pickle weed or cord grass when wetlands drain highway runoff or parking lots.

- Using a large forebay can help to capture the sediment from road sanding.

(Adapted from USEPA 2006)

Summaries of Volume and Pollutant Loading Reductions Achievable

Practice Design

Several design considerations influence the overall performance of stormwater wetlands:

- Sufficient drainage area to maintain water in the permanent pool, which is typically about 25 acres in humid area and more in drier regions.
- Upstream slopes of up to about 15 percent with shallow local slopes large enough to ensure hydraulic conveyance (generally about 3- to 5-foot drop minimum from inlet to outlet).
- Minor design adjustments for regions of karst (i.e., limestone) topography to include an impermeable liner.
- Wetlands can intersect the groundwater table, which might affect pollutant reduction capabilities.
- Incorporation of a sediment forebay, a small pool (typically about 10 percent of permanent pool volume), to trap coarse particles.
- Surface area of the stormwater wetland should be at least 1 percent of the drainage area.
- Length-to-width ratio of at least 1.5:1 to prevent short circuiting.
- Inclusion of both very shallow (<6 inches) and moderately shallow (<18 inches) to provide a longer flow path through the wetland and encourage plant diversity.

(Adapted from USEPA 2006)

Design Variations

There are three basic design variations of constructed wetlands:

- Shallow Marsh: Most of the wetland volume is in the relatively shallow high-marsh or low-marsh depths, with the only deep portions in the forebay at the inlet and the micropool at the outlet. Such systems are appropriate at the terminus of a storm pipe drain or open channel (usually after upland runoff reduction).
- Pond/Wetland System: Combining the wet pond and shallow-marsh designs requires less surface area than the shallow marsh alone because of the relatively deep volume of the wet pond. Such systems are appropriate in moderately to highly urbanized areas.
- Linear Wetland Cells: Systems installed within the conveyance system or zero-order stream channels.

(Adapted from VADCR 2009)

Maintenance Considerations and Resources

Typical maintenance activities are shown in Table 3A1-11 (USEPA 2009).

Table 3A1-11. Constructed wetland maintenance activities

Maintenance activity	Schedule
– Cleaning and removing debris after major storm events (> 2” rainfall) – Harvesting of vegetation when a 50% reduction in the original open water surface area occurs – Repairing embankment and side slopes	Annual or as needed
– Removing accumulated sediment from forebays or sediment storage areas when 60% of the original volume has been lost	5-year cycle
– Removing accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle

Costs and Factors Affecting Cost

The construction cost of urban constructed wetlands varies depending on the design, location, site-specific conditions, and the amount of earthwork and planting. (USEPA Wetlands Fact Sheet 1999). Construction cost estimates and references are provided by EPA in the Menu of BMPs *Stormwater Wetland Fact Sheet:* (http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=74&minmeasure=5).

Table 3A1-12 provides an example of costs taken from North Carolina case studies provided in (Urban Waterways, North Carolina State University Cooperative Extension 2000, www.neuse.ncsu.edu/SWwetlands.pdf).

Unit costs for typical wetlands maintenance items are in Appendix A of EPA’s 2009 *Stormwater Wet Pond and Wetland Management Guidebook* (www.epa.gov/npdes/pubs/pondmgmtguide.pdf)

Example Constructed Wetland Design Manuals in the Chesapeake Bay Watershed Area

Virginia Department of Conservation and Recreation *Stormwater Design Specification No. 13 Constructed Wetlands*, Version 1.6, September 30, 2009.
www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

Table 3A1-12. Sample land and construction costs of a stormwater wetland (taken from North Carolina case studies).

Cost type	Description	Unit cost	Total cost	Cost per acre of watershed treated
Land	Land values can vary from $10,000 to $400,000 per acre in North Carolina. Assume $40,000 at this site.	$40,000/ac	$40,000	$800
Excavation and grading	A total of 4,800 cubic yards (1 acre x 1 yard depth).	$8/cy	$38,400	$770
Hauling	Area adjacent to site used to spread excess earth—costs included excavation costs	Part of above costs	Included in excavation and grading costs	Included in excavation and grading costs
Vegetation	Some local transplants, some natural establishment, and a few ornamental plants from local nursery.	$0.30/sf	$13,000	$260
Spillway and drawdown	Treated lumber used for aesthetic purposes. Drawdown holes drilled through principal spillway.	$0.25/sf	$11,000	$220
Total Land and Construction Costs			**$102,400**	**$2,050**

Note: The table is based on a 1-acre wetland treating a 50-acre watershed.

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VADCR (Virginia Department of Conservation and Recreation). 2009. *Draft VA DCR Stormwater Design Specification No. 13: Constructed Wetlands Version 1.5*, July 2, 2009

Appendix 2: Methods and Tools for Controlling Stormwater Runoff (Quantity and Quality)

This appendix describes various methods, including guidance manuals, and tools for controlling stormwater runoff. This appendix includes

2.1 Methods and Manuals

2.2 Complex Models

2.3 Simpler Models (largely spreadsheet-based or online)

2.1 Methods and Manuals

Nationally Applicable LID Design Methods and Manuals
Prince George's County, Maryland, *Low-Impact Development Design Strategies: An Integrated Design Approach*, EPA-841-B-00-003, 2000. Prince George's County, Maryland, *Low-Impact Development Hydrologic Analysis*, EPA-841-B-00-002, 2000. www.epa.gov/nps/lid
EPA, *Stormwater Best Management Practices Design Guide*, Office of Research and Development, EPA/600/R-04/121, Volumes 1-3 (121, 121A, 121B), September 2004. www.epa.gov/nrmrl/pubs/600r04121/600r04121.htm
Center for Watershed Protection *Urban Subwatershed Restoration Manual Series* (www.cwp.org/Store/usrm.htm) Center for Watershed Protection *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program* (www.cwp.org/Resource_Library/Center_Docs/SW/pcguidance/Manual/PostConstructionManual.pdf)
Water Environment Research Foundation (WERF). *Decentralized Stormwater Controls For Urban Retrofit And Combined Sewer Overflow Reduction* www.werf.org/AM/Template.cfm?Section=Search&Template=/CustomSource/Research/ResearchProfile.cfm&ReportId=03-SW-3&CFID=2715758&CFTOKEN=75805127
WERF. *Critical Assessment of Stormwater Treatment and Control Selection Issues*. In Publication.
Geosyntec Consultants and Wright Water Engineers. *Urban Stormwater BMP Performance Monitoring*. 2009. www.bmpdatabase.org/MonitoringEval.htm
The Low-Impact Development Center, www.lowimpactdevelopment.org; several LID manuals

Federal Facility Design Manuals
EPA Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act, 2009, EPA-841-B-09-001, December 2009, www.epa.gov/owow/nps/lid/section438
U.S. Naval Facilities Engineering Command, *Low Impact Development, Draft, Unified Design Criteria*, UFC 3-210-10, October 2004. www.wbdg.org/ccb/DOD/UFC/ufc_3_210_10.pdf
U.S. Department of Housing and Urban Development, *The Practice of Low Impact Development*, 2003, www.huduser.org/portal/publications/destech/lowImpactDevl.html
U.S. Army Corps of Engineers. *Low Impact Development for Sustainable Installations: Stormwater Design and Planning Guidance for Development within Army Training Areas*. Public Works Technical Bulletin 200-1-62. October 2008.

Transportation-focused LID Design Methods and Manuals
Low Impact Development Center, Inc., 2006, GeoSyntech Consultants, University of Florida, Oregon State University, *Evaluation of Best Management Practices for Highway Runoff Control, Report N. 565 for National Cooperative Highway Research Program (NCHRP), Project 25-20 (1).* http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_565.pdf

Example State/Local Design Manuals and Resources (also refer to individual practice fact sheet references)
The Chesapeake Stormwater Network. *Baywide BMP Design Specifications*. www.chesapeakestormwater.net/baywide-design-specifications2
Pennsylvania. *Stormwater BMP Manual*. 2006. www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305
Delaware. *Standards & Specifications for Green Technology BMPs*. 2005. www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20%26%20Specs_06-05.pdf
District of Columbia. Stormwater Guidebook. http://ddoe.dc.gov/ddoe/frames.asp?doc=/ddoe/lib/ddoe/stormwaterdiv/2009.05.07_SWM_Table_of_Contents.pdf
North Carolina Coastal Federation, www.nccoast.org, resources on implementing LID to protect shellfish beds and coastal beaches.
U.S Fish and Wildlife Service, *Bayscapes*, www.fws.gov/ChesapeakeBay/Bayscapes.htm

BMP Performance Information
WERF. International Stormwater BMP Database. www.bmpdatabase.org
EPA. *Urban BMP Performance Tool*. www.epa.gov/npdes/urbanbmp
Center for Watershed Protection. National Pollutant Removal Performance Database. www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm

Source Control and Pollution Prevention Manuals
EPA *National Management Measures to Control Nonpoint Source Pollution from Urban Areas Office of Oceans, Wetlands and Watersheds*, EPA-841B-05-004, December 2005 (www.epa.gov/owow/nps/urbanmm/)
EPA *The Use of Best Management Practices (BMPs) in Urban Watersheds,* Office of Research and Development, EPA/600/R-04/184, September 2004.
Center for Watershed Protection *Urban Subwatershed Restoration Manual Series, Volume 8, Pollution Source Control Practices,* February 2007 (www.cwp.org/Store/usrm.htm)
Managing Storm Water Runoff to Prevent Contamination of Drinking Water and Managing Highway Deicing to Prevent Contamination of Drinking Water. Steve Ainsworth, USEPA

2.2 Complex, LID-capable Models

Publicly available models appropriate for evaluating LID practices include

- EPA's Storm Water Management Model, version 5 (SWMM5)
- EPA's Hydrologic Simulation Program—FORTRAN model (HSPF)
- U.S. Army Corps of Engineers, Hydrologic Engineering Center—Hydrologic Modeling System (HEC-HMS)
- Western Washington's Hydrology Model, version 3 (WWHM3)
- University of Wisconsin, Civil & Environmental Engineering Department, Water Resources Group—RECARGA

The following summarizes these complex, LID-capable models.

EPA's Storm Water Management Model, version 5 (SWMM5)

EPA's Storm Water Management Model (SWMM) is a dynamic, rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. SWMM5 divides the water balance process into four compartments:

(1) atmosphere (precipitation); (2) land surface (divides precipitation into infiltration, storage, or runoff; (3) groundwater; and (4) transport (pipe and channel flow, as well as storage). It can perform both single event and long-term continuous simulation using precipitation data recorded at hourly or less frequent intervals. The inputs can be supplemented with monthly evaporation data and daily temperature readings. Different hydraulic routing techniques are available to manage from simple to complex routing conditions. Infiltration can be simulated using Horton, Green-Ampt, or Curve Number techniques. These techniques vary in complexity and the availability of the parameters used for their estimation. They can take into account initial soil moisture conditions, hydraulic conductivity, soil moisture capacity, and its regeneration. Separate accounting is provided for runoff from pervious areas and impervious areas, and routing of runoff from one area over another is possible. SWMM5 can simulate pollutant buildup, washoff, and treatment, although those capabilities are not needed to determine predevelopment hydrology comparisons.

SWMM5's advantages are that it uses physically based process models and input parameters wherever possible, it can model any number of storage- or infiltration-based BMPs, it contains robust procedures for routing runoff flow, and it allows models to be built to any level of spatial detail needed to provide the most accurate water balance for a site. A disadvantage is that it does not have the capability to model some BMPs the employ infiltration, storage, and/or flow routing in combination with one another (such as infiltration ponds and vegetated swales).

This model has been in use since 1971 and has undergone several major upgrades since its inception, including expansion of LID applications in 2009. The following applications are discussed in the 2009 manual:

1. Post-Development Runoff
2. Surface Drainage Hydraulics
3. Detention Pond Design
4. Low Impact Development
5. Runoff Water Quality
6. Runoff Treatment
7. Dual Drainage Systems
8. Combined Sewer Systems
9. Continuous Simulation

The model and supporting documentation are at www.epa.gov/ednnrmrl/models/swmm/index.htm.

EPA's Hydrological Simulation Program Fortran (HSPF), and WinHSPF

WinHSPF has broad capabilities for hydraulic, hydrologic, and water quality modeling. BMPs are modeled as either *reaches* that can represent channels or areas of storage, or as *pervious land*. WinHSPF can be used for a single rain event or continuous simulation. In WinHSPF, only the pervious land module can be used for infiltration. Infiltration can vary with time as soil moisture conditions change, and spatial variability in infiltration rates can be addressed. The advantages of WinHSPF include the very broad capabilities for simulating infiltration, surface runoff, groundwater movement, evaporation and evapotranspiration, snowmelt, and for water quality parameters, including temperature (a requirement of Section 438). Another advantage is that it has been incorporated into BASINS, an EPA model that takes advantage of the capabilities of GIS and other systems.

Disadvantages of WinHSPF are its complexity and its limited routing capability compared to SWMM5.

It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The user must input continuous rainfall records to drive the runoff model. Additional records of evapotranspiration, temperature, and solar intensity can be imported for more accurate results. A large number of model parameters can be specified, although default values are provided where reasonable values are available. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at any point in a watershed.

The model and supporting documentation are available for download at www.epa.gov/ceampubl/swater/hspf.

HEC-HMS

HEC-HMS replaces HEC-1 by building on the original capability of simulating precipitation-runoff and routing processes. HEC-HMS added capabilities for distributed modeling and continuous simulation. HEC-HMS includes a broad selection of models for representing rainfall distributions, computing runoff volume (i.e., different selections of infiltration and losses algorithms), for modeling direct runoff (overland flow and interflow); baseflow in a stream; and channel flow. It is capable of modeling either event-based or continuous simulations.

HEC-HMS uses three major components in analyzing a hydrologic system:

1. Basin model—user-entered data on basin data, including losses characteristics and connectivity

2. Meteorological model—user-entered data on rainfall, snowmelt, and evapotranspiration rate

3. Control specifications—user-entered calculation intervals

Precipitation considerations include areal and temporal distribution, and use of radar data. Evapotranspiration and precipitation are represented in the soil-moisture accounting (SMA) model and enables modeling of the drying of the watershed, or otherwise movement of water, between rainfall events for continuous modeling. A five-layer model is used: canopy, surface, soil, upper groundwater, and lower groundwater. Alternatively, there is a deficit-constant method that simplifies to a one-layer model for soil. HEC-HMS divides surfaces into either directly connected impervious areas or pervious surfaces. Losses on the pervious surfaces include interception, infiltration, storage (consisting of canopy, surface, soil-profile, and groundwater), evaporation and transpiration.

HEC-HMS is widely used for simulating distributed infiltration controls, particularly when interactions with streams (with potentially varying baseflows or flash-flows) or input into subsequent river analysis is desired, via HEC-RAS. HEC-HMS also includes extensive elements for modeling engineered structures in management systems for reservoirs, dams, pumps, and other structures.

This model is available for download at
www.hec.usace.army.mil/publications/pub_download.html

WWHM3

WWHM3 is the third edition of the Western Washington Hydrology model developed for Washington State Department of Ecology, with input parameters unique for that region. The model is built on a continuous simulation HSPF platform and can model the entire hydrological cycle for multiple years. The purpose of the WWHM3 is to size stormwater control facilities to mitigate the effects of increased runoff (peak discharge, duration, and volume) from proposed land use changes that affect natural streams, wetlands, and other water courses. WWHM3 also uses an *LID Scenario Generator* to show the mean annual distribution of stormwater into surface runoff, interflow, groundwater, and evapotranspiration. Using the LID Scenario Generator, the user can change land use combinations to optimize performance. The user can also explicitly model various LID practices, including green roofs.

The software has been used to develop stormwater systems for the 19 counties in western Washington State and is designed to comply with the Clean Water Act (NPDES Phase I and II), the Endangered Species Act and state and local stormwater regulations. More information is at www.ecy.wa.gov/Programs/wq/stormwater/wwhmtraining/wwhm/wwhm_v3/index.html.

RECARGA

The RECARGA model was developed by the University of Wisconsin Civil & Environmental Engineering Department Water Resources Group to provide a design tool for evaluating the performance of bioretention facilities, rain garden facilities, and infiltration basins. Individual facilities with surface ponding, up to three distinct soil layers and optional underdrains can be modeled under user-specified precipitation and evaporation conditions. The model continuously simulates the movement of water throughout the facility (ponding zone, soil layers and underdrains), records the soil moisture and volume of water in each water budget term (infiltration, recharge, overflow, underdrain flow, evapotranspiration, and the like) at each time step and summarizes the results. The results of this model can be used to size facilities to meet specific performance objectives, such as reducing runoff volume or increasing recharge, and for analyzing the potential impacts of varying the design parameters. Information is at http://dnr.wi.gov/runoff/stormwater/technote.htm.

2.3 Simpler Models

The following summarizes several simpler, spreadsheet-based or online, models:

Virginia Runoff Reduction Method Spreadsheets

The *Runoff Reduction Method* is a system that incorporates site design, stormwater management planning, and BMP selection to develop the most effective stormwater approach for a given site. The method relies on a three-step compliance procedure that includes (1) applying site design practices to minimize impervious cover, grading, and loss of forest cover, (2) apply runoff reduction practices, and (3) computer pollutant removal by selected BMPs. Two spreadsheets have been developed—one for new development and one for redevelopment projects—that allow the designer to see whether the phosphorus load reduction has been achieved by applying runoff reduction practices. www.dcr.virginia.gov/lr2f.shtml

LID Quicksheet 1.2

Developed by the Milwaukee Metropolitan Sewerage District (MMSD), LID Quicksheet 1.2 is a spreadsheet that has been developed to provide a practical way to calculate how the use of LID practices affect the stormwater detention volume required under Chapter 13. The LID practices included in the Quicksheet are rain gardens, rain barrels, green roofs, cisterns, and permeable pavement. The Quicksheet is intended to allow the designer to evaluate the effect of LID practices on reducing the volume of traditional stormwater detention. Information on LID Quicksheet 1.2 is in Appendix L at http://v3.mmsd.com/manuals.aspx.

Emeryville Stormwater Sizing Calculator

The City of Emeryville, California developed this spreadsheet-based calculator to determine the proper size of stormwater treatment devices for new development projects. The spreadsheet includes seven tables, each targeted to a specific type of stormwater treatment information. The tool uses user-defined drainage area and types to calculate the required facility size for the area. It also calculates the amount of shortfall in metered detention areas, bioretention basins, lowered planter strips, flow-through planter boxes, and bioretention swales. The tool can help track treatment capacity excess and shortages so that parcel areas can be redistributed if there is a shortfall. This tool and others are at http://cfpub.epa.gov/npdes/greeninfrastructure/modelsandcalculators.cfm.

Capitol Region Watershed District (Twin Cities, Minnesota), Volume Reduction Worksheet

This spreadsheet includes formulas for volume reduction practices. Volume credits are provided for seven different types of practices. www.capitolregionwd.org/permit_forms.html

The Center for Neighborhood Technology Green Values Calculator (GVC)

The GVC compares green infrastructure performance, costs, and benefits to conventional stormwater practices at both development-site and neighborhood scales. The tool provides a quantified analysis of green infrastructure environmental benefits including reduced runoff volume and groundwater recharge. Users can specify site data in a custom run or use several templates for typical urban and suburban scenarios. A number of *green interventions* can be selected and used to calculate financial and hydrologic reduction data. Hydrologic reductions include lot-level goals for peak and total discharge, desired total site peak discharge, total detention required, and average annual discharge. The GVC is maintained by The Center for Neighborhood Technology and is at http://greenvalues.cnt.org.

SELECT

The System Effectiveness and Life-cycle Evaluation of Costs Tool (SELECT) is a simple planning-level tool that enables a stormwater manager to examine the effectiveness of alternative scenarios for controlling stormwater pollution and the whole-life cost associated with each scenario. SELECT uses a long-term record of hourly rainfall, which it translates into runoff using a runoff coefficient that is related to the effective imperviousness of the catchment. The runoff is introduced to the BMP (which includes a number of common BMPs, including permeable pavement, wetlands, and swales). If there is capacity in the BMP, the runoff is captured; if the BMP is full, the runoff is discharged untreated to the receiving waters. The model calculates total outflow as the sum of what is treated and what is not.

This tool was developed for the Water Environment Research Foundation (WERF) by a team including ACR, LLC; the University of Utah; and Colorado State University and uses Microsoft Excel as an interface. SELECT is available only to WERF subscribers. More information, including how to become a WERF subscriber and download the tool, is at www.werf.org/select.

Upper Neuse Site Evaluation Tool (SET)

The Upper Neuse Site Evaluation Tool (SET) is a spreadsheet-based tool developed by Tetra Tech, Inc., for the Upper Neuse River Basin Association. It was designed to aid in the assessment of development plans and available BMPs to achieve regional water quality objectives. The SET can also be used to compare the costs of stormwater BMP systems and estimate the cost savings for reducing impervious surfaces within a site design. The most recent version of the SET is at www.unrba.org/set.

The SET has two functioning components—the Hydrology/Pollutant Component for assessing water quality impacts of development, and the Cost Component for assessing the costs of BMPs and other infrastructure. The Hydrology/Pollutant Component requires user-controlled targets for nutrient loading, an optional target for sediment loading, and targets for peak flow for storage of runoff during the type of storm events most likely to cause downstream channel erosion. Data entry includes general site data, land use, drainage areas and BMP information. Various BMPs can be tested to find a combination that meets the targets. The Cost Component allows a user to compare the costs of stormwater BMP systems and estimate the cost savings for reducing impervious surfaces within a site design.

Rainwater Harvester Computer Model

North Carolina State University developed a computer model to assist in determining the appropriate cistern size for a given situation. The model uses rainfall data and anticipated usage to establish cistern inputs and outputs and provides a cost summary and usage statistics in a report form. Version 2.0 includes an improved interface, reduced calculation times, an interactive graph of cistern levels, and the ability to save and load model inputs. Also, the Web site includes a quick online calculator that provides an overview of the benefits of a water harvesting system for homeowners. www.bae.ncsu.edu/topic/waterharvesting/model.html

Appendix 3: Procedures and Case Studies from the Section 438 Guidance

The following information is from the *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act* available at www.epa.gov/owow/NPS/lid/section438.

This appendix includes procedures for calculating the 95th percentile rainfall event, case studies of stormwater designs to retain the 95th percentile rainfall event, and assumptions related to the runoff methodology calculations.

Calculating the 95th Percentile Rainfall Event

A long period of precipitation records, i.e., a minimum of 10 years of data, is needed to determine the 95th percentile rainfall event for a location. Thirty years or more of monitoring data are desirable to conduct an unbiased statistical analysis. The National Climatic Data Center (NCDC) provides long-term precipitation data for many locations of the United States. You can download climate data from its Web site (www.ncdc.noaa.gov) or by ordering compact discs (NOTE: The NCDC charges a fee for access to their precipitation data). Local airports, universities, water treatment plants, or other facilities might also maintain long-term precipitation records. Data reporting formats can vary depending on the data sources. In general, each record should include the following basic information:

- Location (monitoring station)
- Recording time (usually the starting time of a time-step)
- Total precipitation depth during the time-step

In addition to the above information, a status flag is sometimes included to indicate data monitoring errors or anomalies. Typical NCDC flags include A (end accumulation), M (missing data), D (deleted data), or I (incomplete data). If there are no flags, the record has passed the quality control as prescribed by the NCDC and has been determined to be a valid data point.

Several data processing steps are used to determine the 95th percentile rainfall event using a spreadsheet. These steps are summarized below:

1. Obtain a long-term 24-hour precipitation data set for a location of interest (i.e., from the NCDC Web site).

2. Import the data into a spreadsheet. In MS Excel [Data / Import External Data / Import Data]

3. Rearrange all the daily precipitation records into one column if the original data set has multiple columns of daily precipitation records.

	A	B	C	D
1	Date	Prcp		
2	1/2/1921	0.05		
3	1/3/1921	0		
4	1/4/1921	0		
5	1/5/1921	0.33		
6	1/6/1921	0.08		
7	1/7/1921	0.08		
8	1/8/1921	0.19		
9	1/9/1921	0		

4. Review the records to identify if there are early periods with a large number of flagged data points (e.g., erroneous data points). Select a long period of good recording data that represents, ideally, 30 years or more of data. Remove all the extra data (if not using the entire dataset).

5. Remove all flagged data points (i.e., erroneous data points) from the selected data set for further analysis.

6. Remove small rainfall events (typically less than 0.1 inch), which might not contribute to rainfall runoff. Such small events are categorized as depressional storage, which, in general, does not produce runoff from most sites.

	A	B	C	D
1	Date	Prcp		
2	1/5/1921	0.33		
3	1/8/1921	0.19		
4	1/14/1921	1.04		
5	2/6/1921	0.12		
6	2/11/1921	0.63		
7	2/20/1921	1.33		
8	2/28/1921	0.43		
9	3/3/1921	0.13		

Note: Steps 4 through 6 can be processed by applying data sort, delete and re-sort spreadsheet functions. In MS Excel [Data / Sort]

7. Calculate the 95th percentile rainfall amount by applying the PERCENTILE spreadsheet function at a cell. In MS Excel [=PERCENTILE(precipitation data range,95%)]

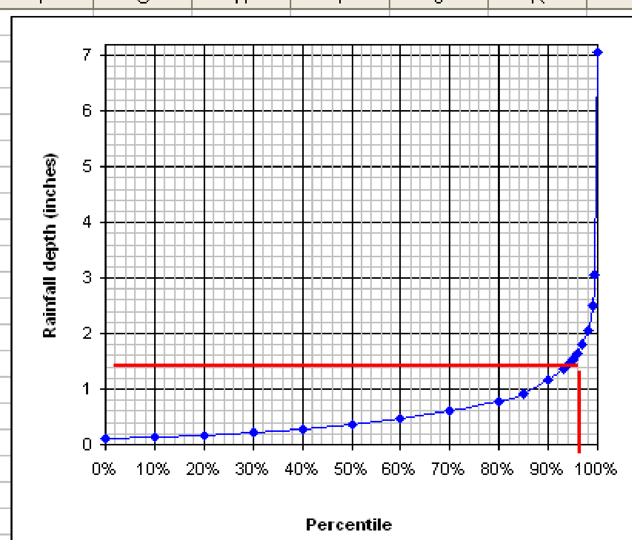
	A	B	C	D	E	F
1	Date	Prcp				
2	1/5/1921	0.33		=PERCENTILE(B:B,95%)		
3	1/8/1921	0.19		1.52		
4	1/14/1921	1.04				
5	2/6/1921	0.12				
6	2/11/1921	0.63				
7	2/20/1921	1.33				
8	2/28/1921	0.43				

Note: The PERCENTILE function returns the n^{th} percentile of value in the entire precipitation data range. This function can be used to determine the 95^{th} percentile storm event that captures all but the largest 5 percent of storms.

8. The 95^{th} percentile was calculated in the previous step. However, if the user would like to see this information represented graphically and get a relative sense of where individual storm percentiles fall in terms of rainfall depths, the following methodology can be used. Derive a table showing percentile versus rainfall depth to draw a curve as shown below. The PERCENTILE spreadsheet function can be used for each selected percent. It is recommended to include at least 6 points between 0 and 100 percent (several points should be between 80 and 100 percent to draw an accurate curve).

	A	B	C	D	E	F	G
1	Date	Prcp		Percentile	Rainfall		
2	1/5/1921	0.33		0%	=PERCENTILE(B:B,D2)		
3	1/8/1921	0.19		10%	=PERCENTILE(B:B,D3)		
4	1/14/1921	1.04		20%	=PERCENTILE(B:B,D4)		
5	2/6/1921	0.12		30%	=PERCENTILE(B:B,D5)		
6	2/11/1921	0.63		40%	=PERCENTILE(B:B,D6)		

	A	B	C	D	E
1	Date	Prcp		Percentile	Rainfall
2	1/5/1921	0.33		0%	0.1
3	1/8/1921	0.19		10%	0.13
4	1/14/1921	1.04		20%	0.17
5	2/6/1921	0.12		30%	0.22
6	2/11/1921	0.63		40%	0.28
7	2/20/1921	1.33		50%	0.36
8	2/28/1921	0.43		60%	0.46
9	3/3/1921	0.13		70%	0.6
10	3/9/1921	0.31		80%	0.79
11	3/13/1921	0.46		85%	0.93
12	3/25/1921	0.47		90%	1.16
13	3/28/1921	0.12		93%	1.35
14	4/1/1921	0.36		94%	1.44
15	4/9/1921	0.69		95%	1.52
16	4/15/1921	0.24		96%	1.65
17	4/17/1921	0.32		97%	1.82
18	4/18/1921	0.55		98%	2.068
19	4/23/1921	0.69		99%	2.508
20	4/24/1921	0.19		99.5%	3.049
21	4/30/1921	1.44		100%	7.06



Use the spreadsheet software to create of plot of rainfall depth versus percentile, as shown above. The 95th percentile storm event should correlate to the rainfall depth calculated in step 7, however the graph can be used to calculate rainfall depths at other percentiles (e.g., 50 percent, 90 percent).

Case Studies on Capturing the 95th Percentile Storm Using On-site Management Practices

Introduction

This section contains nine case studies that are intended to be representative of the range of projects that are subject to the requirements legislated in section 438 of the Energy Independence and Security Act. The facility examples in the case studies were selected to illustrate project scenarios for differing geographic locations, site conditions, and project sizes and types. As noted in Part I, all projects with a footprint greater than 5,000 square feet must comply with the provisions of section 438. What that means is that both new development and redevelopment projects should be designed to infiltrate, evapotranspirate, and/or harvest and use runoff to the maximum extent technically feasible (METF) to maintain or restore the predevelopment hydrology of the site. Scenarios 1–8 are examples of sites where it was technically feasible to design the stormwater management system to retain the 95th percentile storm on-site. Scenario 9, however, was provided as an example of an METF analysis where site constraints allowed the designers to retain only 75 percent of the 95th percentile storm.

Given the site-specific nature of individual projects, the case study scenarios described here do not include site-specific design features such as runoff routing, specific site infiltration rates, the structural loading capacity of buildings and such, in terms of stormwater practice selection.

It should be noted that an example of Option 2, which requires a site-specific hydrologic analysis, has not been provided in this document because of the complexity of factors and the lack of general applicability such an analysis would have.

Background

Numerous approaches exist for determining the volume of runoff to be treated through stormwater management. Retaining stormwater runoff from all events up to and including the 95th percentile rainfall event was identified as Option 1 because small, frequently occurring storms account for a large proportion of the annual precipitation volume. Using GI/LID practices to retain both the runoff produced by small storms and the first part of larger storms can reduce the cumulative impacts of altered flow regimes on receiving water hydrology, e.g., channel degradation and diminished baseflow. For the purposes of this guidance, retaining all storms up to and including the 95th percentile storm event is analogous to maintaining or restoring the predevelopment hydrology with respect to the volume, flow rate, duration and temperature of the runoff for most sites.

Determination of the 95th Percentile Rainfall Event

The 95th percentile rainfall event was determined using the long-term daily precipitation records from the National Climatic Data Center (NCDC 2007). By analyzing the frequency and rainfall depths from daily rainfall records over 24-hour periods, the 95th percentile storm event can be determined. From a frequency analysis viewpoint, the 95th percentile event is the storm event that is greater than or equal to 95 percent of all storms that occur within a given period. Regional climate conditions and precipitation vary across the United States. Because of local values, it is essential that the implementing agency or department establish the 95th percentile storm event for the project site because the control volume could vary depending on local weather patterns and conditions.

On-site Stormwater Management Practice Determinations

For the purposes of the case study scenarios, the following four categories of practices were selected as the most appropriate practices for implementing section 438 requirements: bioretention, permeable pavements and pavers, cisterns, and green roofs. Those practices were selected on the basis of known performance data and cost. For each case study, the same hierarchy of selection criteria was used, i.e., the most cost-effective practices were considered before other practices were considered. Bioretention practices were considered first because those systems generally have the lowest cost per unit of stormwater treated (Hathaway and Hunt 2007). Thus, if the bioretention system could not be designed to adequately capture the desired runoff volume, permeable pavement and pavers, cisterns, and green roofs were considered in that order according to relative cost. In most cases, a combination of practices was selected as part of an integrated treatment system. It should be noted that all treatment systems were designed to accomplish the goal of capturing the 95th percentile rainfall event on-site. Examples of on-site stormwater management practices selected for each site are presented in the results section. For the Boston, Massachusetts, site, it was assumed that bioretention was not feasible to simulate a situation where space was severely limited; as a result, interlocking modular pavers were selected as the most cost-effective stormwater management to capture the requisite design volume. To further illustrate the range of site conditions designers might encounter and how site conditions affect the selection of appropriate control options, Scenario #3 (Cincinnati, Ohio) was re-analyzed as Scenario #8. In Scenario #8, it was assumed that the site had clay soils and low infiltrative capacity. Given those site conditions, the range of potential control options was more limited and a combination of modular paving blocks, a green roof, and cisterns was ultimately selected because of cost and site suitability factors.

For purposes of these modeling exercises, a number of assumptions were associated with each category of practice. The assumptions are not necessarily an endorsement of a particular design paradigm, but rather were used to keep a somewhat conservative cap on the scenarios to demonstrate the feasibility of the approach. For example, bioretention retrofits can and should often be located in prior impervious locations; however, in all modeled scenarios bioretention was restricted to currently landscaped areas. The assumptions are as follows:

- **Bioretention areas**: On-lot retention of stormwater through the use of vegetation, soils, and microbes to capture, treat and infiltrate runoff.

  It is assumed bioretention practices would be installed within landscaped pervious areas or that pervious areas would be created for bioretention cells. While termed bioretention, these systems are designed to provide infiltration and temporary storage. Bioretention areas would be designed to accept up to a depth of 10 inches of water across the surface of the bioretention cell (see Resources at end of this Appendix). The conceptual design of this storage depth would occur within the media and/or could be included as ponded storage. Further design storage beyond the 10 inches would be acceptable (and encouraged) above the media on a site-by-site basis with ponded depth generally not to exceed 12 inches.

  Uniform infiltration was assumed across the entire base of the bioretention cell. No additional media underneath the amended soils were included in the designs with infiltration rates in this layer governed by the in situ soils. Underdrains were not modeled directly but could be applied at the point of storage overflow such that no overflow occurs until the design depth of 10 inches is saturated. This approach was selected to maximize the storage and infiltration benefits of these systems. Designs using underdrains at the base of the bioretention cell do not store the requisite volumes because the media is permeable and the underdrain conveys the runoff off-site through the underdrain before it can be infiltrated. Because standard underdrains typically discharge from smaller storms as well, underdrain designs, if employed, should ensure adequate retention capacity for the 95th percentile event volume.

  The bioretention footprint for modeling purposes was calculated as one uniform area that did not include side slopes. There is an expectation that actual bioretention cell construction would be distributed throughout the site with targeted locations based on hydrology (natural flow paths) and soils with greater infiltrative capacity. Side slopes can increase the surface excavation area required to accommodate the footprint and freeboard of these systems depending on the design or the bioretention system.

- **Porous/permeable pavement**: Transportation surfaces constructed of asphalt, concrete or permeable pavers that are designed to infiltrate runoff.

  Infiltration was modeled for the entire porous pavement area with drainage pipes used only as overflow outlets. This design was chosen to maximize infiltration capabilities of the system. While many types of porous pavement systems can be used, modular block type pavers were generally applied in this design category under the assumption that they typically include sufficient volumetric storage in the media layer. [Note: Other types of porous pavement applications are available that support heavy loads and can be designed to temporarily store and infiltrate runoff beneath the surface of the pavement.]

For these systems, an equivalent of 2 inches of design storage depth was assumed. This design depth could be achieved by specifying 10 inches of media depth that had 20 percent void space. Similarly, this could be achieved by designing 6 inches of media depth above the bottom surface, with specified media containing 33 percent void space. This alternative would have the overflow outlet at the 6-inch depth providing an equivalent water storage depth of 2 inches.

The soils under the paver blocks could require or be subjected to some compaction for engineering stability. As a result, infiltration into underlying soils was modeled conservatively by applying the minimum infiltration rate for each soil type (see Resources at end of this Appendix).

Generally, porous pavement is not recommended for high traffic areas or loading bays Because of that, the scenarios assume that only a percentage of total parking and road areas on a site can be converted to porous pavement. The assumed maximum percentage applied in the scenarios was set at 60 percent of the total paved area. Guidance on porous pavements is at:
http://cfpub.epa.gov/npdes/greeninfrastructure/technology.cfm#permpavements

- **Cistern**: Containers or vessels that are used to store runoff for future use.

  Cisterns were modeled in cases where green roofs were not feasible or where it was necessary to include additional storage volume to meet the goal of on-site rainfall runoff capture. The sizes of cisterns would be calculated on the basis of site-specific rainfall, site-specific spatial and structural conditions, use opportunities and rates, and consideration of cost per volume of storage. For simplicity, cistern volume was reported as a total volume. This total volume could be subdivided into any number of cisterns to provide the total necessary storage but should be based on the impervious area and runoff quantities which will flow to the cistern. The most efficient cost per volume storage would need to be considered on a site-by-site basis (see Resources at end of this Appendix).

- **Green roof**: Roof designed with lightweight soil media and planted with vegetation.

  Frequently, green rooftop area is limited by structural capacity. In addition, other rooftop equipment might need to be accommodated in this space including HVAC systems and air handlers. For that reason, and to provide a somewhat conservative rate of application, it was assumed for these modeling analyses that up to 30 percent of a roof's impervious area could be converted into a green roof. Green roof area was assumed to have one inch of total effective stormwater storage, i.e., a 2.5-inch media depth with 40 percent void space (see the Resources at end of this Appendix).

General Approach

Using site aerial photos, spatial analysis should be conducted to estimate the land cover types and areas for each site. The surface conditions of each site can be digitized using geographic information systems (GIS) techniques. Alternatively, computer-aided design (CAD) drawings can be used to estimate the surface area of each land cover type. The schematic in Figure 3A3-1 illustrates the processes used for selecting and determining the overall size of stormwater management practices for each site.

The following steps provide more detailed information on acquiring and calculating the necessary data to complete the processes indicated in Figure 3A3-1. This methodology was used in the scenario analyses that follow.

Collecting spatial data for a site

1. Collect an aerial orthophotograph for the desired site.
2. Digitize land use/land cover conditions using GIS techniques. If CAD drawings of the site exist, they can be used to estimate land cover area (pervious, impervious).
3. Categorize the digitized or planned land use/land cover according to surface hydrologic conditions, e.g., rooftop, pavement, and pervious/landscaped area.
4. Estimate the size of each land use/land cover category (by polygon).

Determining the 95th percentile, 24-hour rainfall event

1. Obtain a long-term, 24-hour precipitation data set for the location of interest (i.e., from the NCDC Web site or other source).
2. Import the data into a spreadsheet. In MS Excel [Data / Import External Data / Import Data]
3. Rearrange all the daily precipitation records into one column if the original data set has multiple columns of daily precipitation records.
4. Remove all flagged data points (i.e., erroneous data points) from the selected data set for further analysis.
5. Remove small rainfall events (typically less than 0.1 inch) that might not contribute to rainfall runoff. These small storms often produce little if any appreciable runoff from most sites and for modeling purposes are typically considered as volume captured in surface depression storage.

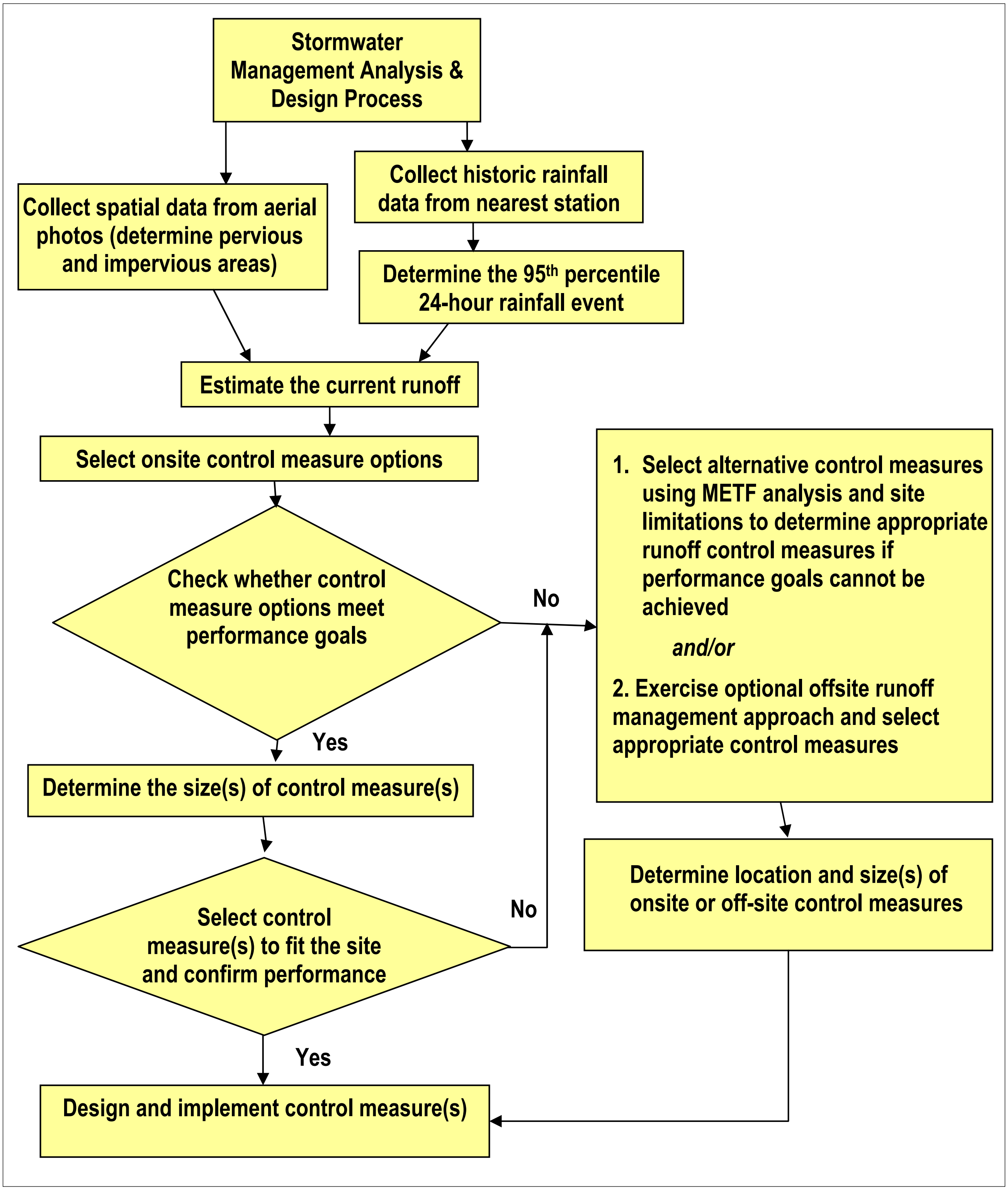


Figure 3A3-1. Flow chart depicting the process for determining control measures using the 95th percentile, 24-hour annual rainfall event.

6. Calculate the 95th percentile rainfall volume by applying the PERCENTILE spreadsheet function to a range of data cells. The PERCENTILE function returns the nth percentile value in the specified precipitation data range. This function can be used to determine the 95th percentile storm event that captures all but the largest 5 percent of storms. In MS Excel [PERCENTILE(precipitation data range, 95%)]

Estimating current runoff and placing on-site control measures to capture the 95th percentile rainfall event

1. Collect spatial data for a site, e.g., rooftop, pavement, and pervious areas as above.

2. Check soil type (USDA mapping, borings, or on-site testing) for the site to determine infiltration parameters. For this modeling, many of the assumptions that pertain to generalized soils groups and their infiltration properties come from the EPA Stormwater Management Model (SWMM 4.x) manual (see Resources at end of this Appendix).

3. Determine the current runoff volume that would occur during a 24-hour period by applying the 95th percentile rainfall to the existing site conditions (land use and soil properties) as above using a hydrologic model (such as TR-55 or SWMM). For this analysis, it is assumed that the rainfall amount is distributed over a 24-hour period. Actual rainfall event duration (and intensity) was not considered for determining rainfall runoff (however, timing was considered when modeling infiltration).

4. Determine flow paths so that management practice placements are in locations where flows can be intercepted and routed to practices. Because this is a site-specific effort and might require detailed topographic information or further surveys, this would be a task to be completed on-site and therefore is not included as a part of the modeling scenario exercise.

5. Select on-site control practices to capture the current 95th percentile runoff event; base the selection of appropriate options on site conditions, areas available for treatment options, and other factors such as site use and other constraints.

Note: The steps above have been generalized for the purposes of this guidance. It is recommended that a qualified professional engineer determine or verify that stormwater management practices are sized, placed, and designed correctly. Note also that the methodology to determine rainfall amount used a 24-hour period from daily records. Actual rainfall events might have occurred over shorter or longer periods. Similarly, for modeling purposes, the 24-hour rainfall amount was distributed to pervious and impervious areas (and management practices) as a uniform event occurring during a 24-hour period. A large data set (greater than 50 years) was used to reasonably represent rainfall depth on a daily basis. It stands to reason that more frequent, shorter duration precipitation events are better represented than less frequent, longer duration precipitation events.

Scenarios

Eight locations were selected for the 9 case studies as shown in Figure 3A3-2 and Table 3A3-1. Case study numbers 3 and 8 were both developed using the Cincinnati, Ohio, facility; although the site parameters were altered to represent differing site conditions and design constraints. Annual average rainfall depths for those locations range from 7.5 inches to 48.9 inches. Analyses of the 95th percentile rainfall events for the locations produced rainfall depths that range from 1.00 inch to 1.77 inches (Table 3A3-1).

Figure 3A3-2. Locations for analyzing on-site control measures.

The government facilities in the 8 case study locations were selected because they represent generic sites from the major climatic regions of the United States. The facilities also were selected because the sites have a range of site characteristics that can be used to illustrate different site designs and stormwater management options, e.g., pervious, roof, and pavement areas (Table 3A3-2). Site sizes range from 0.7 to 27 acres, with percent site imperviousness area ranging from 47 to 95 percent of the site. Aerial photos of the sites are included along with site-specific rainfall runoff and soil results.

Table 3A3-1. Summary of rainfall data for the seven locations

No	Location	NCDC daily precipitation data		Rainfall depth (inches)	
		Period of record	Coverage	Annual average	95th percentile rainfall event
1	Charleston, WV	1/1/1948–12/31/2006 (59 yrs)	99%	43.0	1.23
2	Denver, CO	1/1/1948–12/31/2006 (59 yrs)	96%	15.2	1.07
3	Cincinnati, OH	1/1/1948–12/31/2006 (59 yrs)	96%	36.5	1.45
4	Portland, OR	1/1/1941–12/31/2006 (66 yrs)	98%	35.8	1.00
5	Phoenix, AZ	1/1/1948–12/31/2006 (59 yrs)	99%	7.5	1.00
6	Boston, MA	1/1/1920–12/31/2006 (87 yrs)	99%	41.9	1.52
7	Atlanta, GA	1/1/1930–12/31/2006 (77 yrs)	100%	48.9	1.77
8	Norfolk, VA	1/1/1957–12/31/2006 (50 yrs)	99%	45.4	1.68

The results of the spatial analyses were summarized and divided into three land cover categories; rooftop, pavement, and pervious area, as shown in Table 3A3-2.

Table 3A3-2. Summary of land-use determinations of the study sites

No	Location	Facility spatial info (acres)				Site imperviousness
		Rooftop	Pavement	Pervious	Total	
1	Charleston, WV	0.1	0.4	0.2	0.7	73%
2	Denver, CO	0.5	1.9	2.0	4.5	55%
3	Cincinnati, OH	1.6	8.0	9.4	19	51%
4	Portland, OR	8.8	16.9	1.3	27	95%
5	Phoenix, AZ	0.2	0.7	1.1	2	47%
6	Boston, MA	0.9	1.5	1.1	3.5	69%
7	Atlanta, GA	3.9	10.8	6.2	21	70%
8	Norfolk, VA	0.9	0.55	0.15	1.6	91%

Methods for Determining Runoff Volume

Direct Determination of Runoff Volume

Runoff from each land cover was estimated using a simplified volumetric approach using the following equation:

Runoff = Rainfall – Depression Storage – Infiltration Loss

Again, this methodology does not consider routing of runoff; therefore, slope is not considered when calculating on a volumetric basis.

Infiltration loss is calculated only in pervious areas (e.g., there is no infiltration in impervious areas). In this analysis, infiltration was estimated using Horton's equation:

$$Ft = f_{min} + (f_{max} - f_{min})\ e - k\ t$$

where

Ft = infiltration rate at time t (in/hr)
f_{min} = minimum or saturated infiltration rate (in/hr)
f_{max} = maximum or initial infiltration rate (in/hr)
k = infiltration rate decay factor (/hr) and
t = time (hr) measured from time runoff first discharged into infiltration area

Infiltration loss for the 24-hour rainfall duration was estimated by the following equation with assumptions of a half hour Δt and uniform rainfall distribution in time:

$$Infiltration\ Loss = \sum (f \cdot \Delta t)$$

To more accurately describe the dynamic process of infiltration associated with Horton's equation, infiltration loss was integrated over a 24-hour period using a half hour time step while applying the maximum and minimum infiltration rates (in/hr) with time using the appropriate soil decay factor. The results of this process are further illustrated in the Resources section at the end of this Appendix.

Once runoff from each land cover was estimated, the total runoff from a site can be obtained using an area-weighted calculation as shown below:

$$Runoff_{site} = \{(Runoff_{roof} \times A_{roof}) + (Runoff_{pavement} \times A_{pavement}) + (Runoff_{pervious} \times A_{pervious})\} / A_{site}$$

Where $Runoff_{site}$ = total runoff from the site (inches); A_{site} = site area (acres); $Runoff_{roof}$ = runoff from rooftop (inches); A_{roof} = rooftop area (acres); $Runoff_{pavement}$ = runoff from pavement area (inches); $A_{pavement}$ = pavement area (acres); $Runoff_{pervious}$ = runoff from pervious area (inches); and $A_{pervious}$ = pervious area (acres).

An example demonstrating how to calculate runoff by applying the Direct Determination method is presented below using the Charleston, WV (Scenario #1) site condition presented in Tables 3A3-1 and 3A3-2.

$$
\begin{aligned}
Runoff_{\text{roof}} &= \textit{95th Rainfall} - \textit{Depression Storage} \\
&= 1.23 - 0.1 = 1.13 \text{ inches} \\
Runoff_{\text{pavement}} &= \textit{95th Rainfall} - \textit{Depression Storage} \\
&= 1.23 - 0.1 = 1.13 \text{ inches} \\
Runoff_{\text{pervious}} &= \textit{95th Rainfall} - \textit{Depression Storage} - \textit{Infiltration Loss} \\
&= 1.23 - 0.1 - 9.73 = 0 \text{ inches (i.e., no runoff because the result is a negative number)}
\end{aligned}
$$

$$
\begin{aligned}
Runoff_{\text{site}} &= \{(Runoff_{\text{roof}} \times A_{\text{roof}}) + (Runoff_{\text{pavement}} \times A_{\text{pavement}}) + (Runoff_{\text{pervious}} \times A_{\text{pervious}})\} / A_{\text{site}} \\
&= \{(1.13 \times 0.10) + (1.13 \times 0.41) + (0 \times 0.19)\} / 0.7 = 0.82 \text{ inches}
\end{aligned}
$$

Infiltration loss was estimated on the basis of soil type B by applying the Horton equation as described above. Because the volume removed from surface runoff through infiltration was substantial, no runoff occurred from the pervious area.

In cases where sites had limited physical space available for stormwater management, a series of practices was used (e.g., treatment train) to simulate the runoff and infiltrative behavior of the system. For example, if there was inadequate area and infiltrative capacity to infiltrate 100 percent of the 95th percentile storm event within a bioretention system, another on-site management practice was selected to manage the runoff that could provide the necessary capacity. In such a manner, excess runoff was routed to another management practice in the series of treatment cells where possible.

Two types of soils were considered for every site: hydrologic soil groups B and C (except for scenario 8 in which hydrologic soil group D was used). Group B soils typically have between 10 and 20 percent clay and 50 to 90 percent sand and either loamy sand or sandy loam textures with some loam, silt loam, silt, or sandy clay loam soil textures placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. Group C soils typically have between 20 and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam soil textures with some clay, silty clay, or sandy clay textures placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments (USDA-NRCS 2007). The application of these hydrologic soil groups was intended to give reasonable and somewhat conservative estimates of infiltration capacity.

General hydrologic parameters in this analysis were assumed as follows (see Resources at the end of this Appendix for citations of assumptions):

- Depression storage (or initial abstraction)
  - Rooftop: 0.1 inches
  - Pavement: 0.1 inches

  - Pervious area: 0.2 inches
- Horton Infiltration parameters
  - Hydrologic Soil Group B
  - Maximum infiltration rate: 5 in/hr
  - Minimum infiltration rate: 0.3 in/hr
  - Decay factor: 2 /hr
  - Hydrologic Soil Group C
  - Maximum infiltration rate: 3 in/hr
  - Minimum infiltration rate: 0.1 in/hr
  - Decay factor: 3.5 /hr
- Design storage assumptions of control measures
  - Bioretention: up to 10 inches (but variable based on balancing necessary storage volume, media depth for plant survivorship, and surface area limitations)
  - Green roof: 1 inch (2.5 inches deep media with 40 percent void space)
  - Porous pavement: 4 inches (10 inches deep media with 40 percent void space)

Other Methods for Estimating Runoff Volume

Runoff from a site after applying the 95th percentile storm can be estimated by using a number of empirical, statistical, or mathematical methods. Several methods were considered in this analysis. The Rational Method can be used to estimate peak discharge rates and the Modified Rational Method can be used to develop a runoff hydrograph. The NRCS TR-55 model can be used to predict runoff volume and peak discharge. TR-55 can also be used to develop a runoff hydrograph. The EPA Stormwater Management Model (SWMM) can be used to simulate rainfall-runoff, pollutant buildup and wash-off, transport-storage-treatment of stormwater flow and pollutants, backwater effects, and such for a wide range of temporal and spatial scales. The SWMM model can be fit to model a small site with a distributed system. Hydrologic Simulation Program – Fortran (HSPF, USDA) is a watershed and land use based lumped model that can be used to compute the movement of water and pollutants when evaluating the effects of land use change, reservoir operations, water quality control options, flow diversions, and such. In general, regionally calibrated modeling parameters are incorporated into HSPF. QUALHYMO is a complete hydrologic and water quality model that can be used to factor in snowmelt or soil moisture conditions or to simulate system behavior on the basis of infiltration and ET, groundwater storage tracking, baseflow and deep volumetric losses, and other variables.

Many of the existing tools for analyzing distributed systems use some part or all of the principles or formulae of the modeling approaches highlighted above. For example, the Emoryville spreadsheet control measure model (Emoryville, California) uses a runoff coefficient (i.e., Rational Method) for analyzing lot-level to neighborhood-scale control measure sizing. The Green Calculator (Center for Neighborhood Technologies) estimates the benefit of on-site GI/LID options on a neighborhood-scale by applying the curve numbers (i.e., TR-55) and the Modified Rational Method. The Northern Kentucky Spreadsheet Tool uses a TR-55-based approach for control measure sizing on neighborhood or site level spatial scales. The WWHM (Western Washington Hydrology Model) is a regionally calibrated HSPF model intended for use in sizing stormwater detention and water quality facilities to meet the Washington State Department of Ecology standards. WBM-QUALHYMO is a Canadian model used in conjunction with the Water Balance Model (WBM). This model can be used to continuously simulate stormwater storage routing, stream erosion, drainage area flow routing, and snowmelt runoff (and ultimately freeze-thaw). Table 3A3-3 contains a summary of these different methods based on generic modeling features.

Table 3A3-3. Potential methods for analyzing control measures

Model considerations		Rational method	TR-55	SWMM	Direct determination	HSPF	QUALHYMO
Temporal scale	Single Event	Yes	Yes	Yes	Yes	Yes	Yes
	Continuous Simulation	No	No	Yes	Possible	Yes	Yes
Spatial scale	Lot-level	Yes	Yes[b]	Yes	Yes	No	No
	Neighborhood	Yes	Yes	Yes	Yes	Possible	Possible
	Regional	Yes	Yes[c]	Yes	No	Yes	Yes
Outputs	Peak Discharge	Yes	Yes	Yes	No	Yes	Yes
	Runoff Volume	Yes	Yes	Yes	Yes	Yes	Yes
	Hydrograph	Yes[a]	Yes	Yes	No	Yes	Yes
	Water Quality	No	No	Yes	Possible	Yes	Yes

[a] Modified Rational Method

[b] No less than 1 acre.

[c] No more than 25 square miles (up to 10 subareas).

From the viewpoint of modeling both lot-level and neighborhood scale projects, the Rational Method, NRCS TR-55, SWMM, and Direct Determination approaches were selected for use in scenario analyses. The strengths and weaknesses of the methods are presented in Table 3A3-4.

Table 3A3-4. Comparison of approaches for determining runoff volume

Method	Strengths	Weaknesses
Direct determination	• Methodology for runoff determination is same as SWMM • Models basic hydrologic processes directly (explicit) • Simple spreadsheet can be used	• Direct application of Horton's method can estimate higher infiltration loss, especially at the beginning of a storm • Does not consider flow routing
Rational method	• Method is widely used • Simple to use and understand	• Cannot directly model storage-oriented on-site control measures
TR-55	• Method is widely used • Simple to use and understand	• Might not be appropriate for estimating runoff from small storm events because depression storage is not well accounted for
SWMM	• Method is widely used • Can provide complete hydrologic and water quality process dynamics in stormwater analysis	• Needs a number of site-specific modeling parameters • Generally requires more extensive experience and modeling skills

Each method requires specific parameters for estimating runoff from a site. Runoff coefficients for the Rational Method are assumed to be 0.9 for rooftop and pavement areas, and 0.1 and 0.135 for Group B and C soil pervious areas, respectively (Caltrans 2003). The slope of the pervious area was assumed to be an average of 2 percent. Applying those runoff coefficients for each surface, the overall area-weighted runoff coefficient can be determined.

When applying the NRCS TR-55 method, Curve Numbers (CNs) should be determined for each drainage area. For rooftop and pavement areas the CN was assumed to be 98, and pervious area CN was determined on the basis of the hydrologic soil group and the status of grass cover condition. Curve numbers for pervious areas were assumed to be 61 and 74 for Group B and C soils, respectively, with an assumption of over 75 percent grass cover. The overall CN can be estimated by using an area-weighted calculation (USDA-SCS 1986).

In SWMM modeling, infiltration was modeled using Horton's equation. The same infiltration parameters and depression storage values used in the direct determination method of runoff treatment volume described earlier were applied to the SWMM analyses. The average slope of the pervious area was again assumed to be 2 percent. The same uniform rainfall distribution and time step was applied for the SWMM model runs.

Runoff Methodology Results

Stormwater management practice sizes (and depth) were determined using the Direct Determination approach to capture the volume of runoff generated in a 95th percentile rainfall event at each location. Total acreage, impervious area, the 95th percentile rainfall event, the current expected runoff for the 95th percentile rainfall event, and the future runoff with stormwater management controls were reported for each site. Results were summarized for the two soil types (three soil types for Scenarios #3 and #8 in Cincinnati). The spatial location of on-site control measures was also illustrated in the site aerial photo figures. Note that site practices were placed only on undeveloped or landscaped areas without regard for true flow paths or technical feasibility. It might be preferrable to place practices in existing impervious areas, if possible. For the purposes of this modeling exercise, the least cost and most practical solutions were used, i.e., locating bioretention systems on undeveloped or landscaped areas. On an actual site, flow paths would be determined and berms and swales might be used to route runoff to areas that are most suitable for infiltration. In other cases, areas that are impervious could be modified to accept runoff, e.g., impermeable pavements removed and replaced by permeable, sidewalks could be redesigned to include sidewalk bioretention cells, and streets could be designed with flow through or infiltration curb bumpouts/raingardens.

To compare other approaches of runoff estimation, alternate methodologies were also employed for three scenarios. TR-55 was used for Scenario #1 (Atlanta), the Rational Method was applied to Scenario #2 (Denver), and the SWMM was run for Scenario #7 (Charleston).

Although flood control is not the focus of this guidance, most localities have flood control requirements that will need to be considered in designing control measures to comply with section 438. For flood control purposes, TR-55 was used to model the 10-year frequency design storm for each site under the assumption that all stormwater management practices were in place. The 10-year design storms were selected from the NRCS TR-55 Manual (USDA 1986) for both the Eastern U.S. and the Western U.S. Precipitation Frequency Maps (www.wrcc.dri.edu/pcpnfreq.html). The 10-year frequency design storm was selected because it represents a common design standard used by state and local governments to manage peak rates of runoff and prevent flooding.

Cost Estimates for Selected Scenarios

Scenario numbers 2 and 7 include cost estimates comparing the capital costs for a design to comply with section 438 (retention of the 95th percentile rainfall event) and capital costs for a traditional stormwater management design (e.g., typical curb and gutter, off-site pond for stormwater management). These costs are based on average unit costs to construct both traditional and GI/LID controls.

Scenario #1 – Charleston, West Virginia

A 0.7-acre site with 73 percent impervious area was selected from Charleston, West Virginia (Figure 3A3-3). If the 95th percentile rainfall event (1.23 inches) occurred on the existing site (i.e., with no control measures), 0.82 inch of runoff using the Direct Determination method would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.03 acre if hydrologic soil group B is present, or 0.06 acre if hydrologic soil group C (Table 3A3-5) is the predominant soil type on the site. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 0.2 acre of pervious area would be available for placing bioretention systems. The effective design storage depth within the designated bioretention area was 8 inches.

Figure 3A3-3. Actual site and on-site control measures (Charleston, WV).

Table 3A3-5. Estimated sizes of on-site control measures for Scenario #1 (Charleston, WV)

Total Area (acres)		0.7	
Estimated Imperviousness (%)		73%	
95^{th} Percentile Rainfall Event (inches)		1.23	
Expected Runoff for the 95^{th} Percentile Rainfall Event (inches)		0.82	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by Direct Determination method (acres)		0.03	0.06
Bioretention estimated by SWMM (acres)		0.03	0.05
Off-site storage necessary to control the 10-yr event of 3.9 inches (acre-ft)	With on-site controls	0.10	0.12
	Without on-site controls	0.16	0.17

Note: The two hydrologic methods used (direct determination and SWMM) estimated similar bioretention sizes.

Scenario #2 – Denver, Colorado

A 4.5-acre site with 55 percent impervious area was selected from Denver, Colorado (Figure 3A3-4). If the 95th percentile rainfall event (1.07 inches) occurred on the existing site (i.e., with no control measures), 0.53 inch of runoff from the site would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.16 acre if the hydrologic soil group B is present or 0.3 acre if hydrologic soil group C (Table 3A3-6) is the predominant soil type on the site. Assuming that bioretention practices are placed only in areas that are currently pervious or landscaped, a total of 2 acres of pervious area is available for placing bioretention systems. The design storage depth of media within the designated bioretention area was 6 inches.

Figure 3A3-4. Actual site and on-site control measures (Denver, CO).

Table 3A3-6. Estimated sizes of on-site control measures for Scenario #2 (Denver, CO)

Total Area (acres)		4.5	
Estimated Imperviousness (%)		55%	
95th Percentile Rainfall Event (inches)		1.07	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.53	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination method (acres)		0.16	0.3
Bioretention estimated by Rational Method (acres)		0.16	0.28
Off-site storage necessary to control the 10-yr event of 3.2 inches (acre-ft)	With on-site controls	0.35	0.52
	Without on-site controls	0.64	0.64

Cost estimates were also developed for this scenario (Table 3A3-7) to compare the costs of installing on-site control measures to retain the 95th percentile rainfall event versus the costs to install traditional stormwater management controls (e.g., curbs and gutters combined with off-site retention such as extended detention wet ponds). In a GI/LID scenario, the bioretention cell would occupy a specified area. This same area in a traditional design would be covered in turf because the pond would typically be off-site and not occupy the area planted in turf. Table 3A3-7 includes this cost under the traditional column. Note: typical land development practices involve mass clearing and grading so little or no preexisting vegetation is typically retained. It is also assumed that the use of GI/LID practices would require less underground infrastructure because the traditional design typically routes stormwater underground to an off-site pond via pipes or culverts while GI/LID practices are designed to manage runoff on-site and as close to its source as possible. They are also dispersed across the site and routing occurs through surface drainage via bioswales and overland flow. As a result GI/LID practices do not require as much or any hard or grey infrastructure. The cost estimates were developed for Hydrologic Soil Group B.

Table 3A3-7. Estimated costs for Scenario #2 (Denver, CO)

Sizes of on-site control practices			
		Controls for 95th Percentile Event	Traditional Stormwater Controls
Rainfall depth (in)		1.07	
Bioretention (acres)		0.1	
Paver blocks (acres)		0	
Green roof (acres)		0	
Off-site Pond	WQV (ac-ft)	--	0.18
	10-Yr Fld Cntr (ac-ft)	0.15	0.14
Total Off-Site Requirement (ac-ft)		0.15	0.32
Land Area (assumes avg 3 ft depth)		0.05	0.11
% of the site		2.8%	
Costs of on-site control practices			
Biorention/alternative		$32,495	$4,187
Off-site Pond	WQV (ac-ft)		$14,833
	10-Yr Fld Cntr (ac-ft)	$10,073	$9,527
Infrastructure	Pipe	$8,990	$16,982
	Inlet	$9,920	$14,880
Land Area (assumes $300K/acre)		$14,500	$31,500
Sum		**$75,978**	**$91,909**
% difference from Traditional		**-17.3%**	

Scenario #3 – Cincinnati, Ohio

A 19-acre site with 51 percent impervious area was selected in Cincinnati, Ohio (Figure 3A3-5). If the 95th percentile rainfall event (1.45 inches) occurred on the existing site (i.e., no control measures were in place), 0.68 inch of runoff from the site would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.8 acre if the hydrologic soil group B is present or 1.3 acres if hydrologic soil group C (Table 3A3-8) is the predominant soil type on the site. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 9.4 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 8 inches.

Figure 3A3-5. Actual site and on-site control measures (Cincinnati, OH).

Table 3A3-8. Estimated sizes of on-site control measures for Scenario #3 (Cincinnati, OH)

<table>
<tr><td colspan="2">Total Area (acres)</td><td colspan="2">19</td></tr>
<tr><td colspan="2">Estimated Imperviousness (%)</td><td colspan="2">51%</td></tr>
<tr><td colspan="2">95th Percentile Rainfall Event (inches)</td><td colspan="2">1.45</td></tr>
<tr><td colspan="2">Expected Runoff for the 95th Percentile Rainfall Event (inches)</td><td colspan="2">0.68</td></tr>
<tr><td colspan="2" rowspan="2">Stormwater Management Area Required</td><td colspan="2">Hydrologic Soil Group</td></tr>
<tr><td>B</td><td>C</td></tr>
<tr><td colspan="2">Bioretention estimated by the Direct Determination (acres)</td><td>0.8</td><td>1.3</td></tr>
<tr><td rowspan="2">Off-site storage necessary to control the 10-yr event of 4.2 inches (acre-ft)</td><td>With on-site controls</td><td>2.42</td><td>3.24</td></tr>
<tr><td>Without on-site controls</td><td>3.29</td><td>3.73</td></tr>
</table>

Scenario #4 – Portland, Oregon

A 27-acre site with 95 percent impervious area was selected in Portland, Oregon (Figure 3A3-6). If the 95th percentile rainfall event (1.0 inch) occurred on the existing site (i.e., no control measures), 0.86 inch of runoff would be generated and require management. The site has the greatest imperviousness among the seven sites.

Given the site conditions, there is not enough pervious area to manage the entire runoff volume discharged by the 95th percentile rainfall event with bioretention. As a result, other practices were evaluated and selected. The practices integrated into the design included a green roof, cisterns, and porous pavement. On the basis of the technical considerations of constructing and maintaining control measures at the site, it was assumed that approximately 30 percent of the available pervious area could be converted into bioretention cells; 20 percent of total rooftop area could be converted into green roofs; 40 percent of paved area could be converted into paver blocks; and 50,000 gallons of total volume could be captured in cisterns for use on this urbanized site. Using this system of four different practices, all runoff for the 95th percentile rainfall event would be retained (Table 3A3-9).

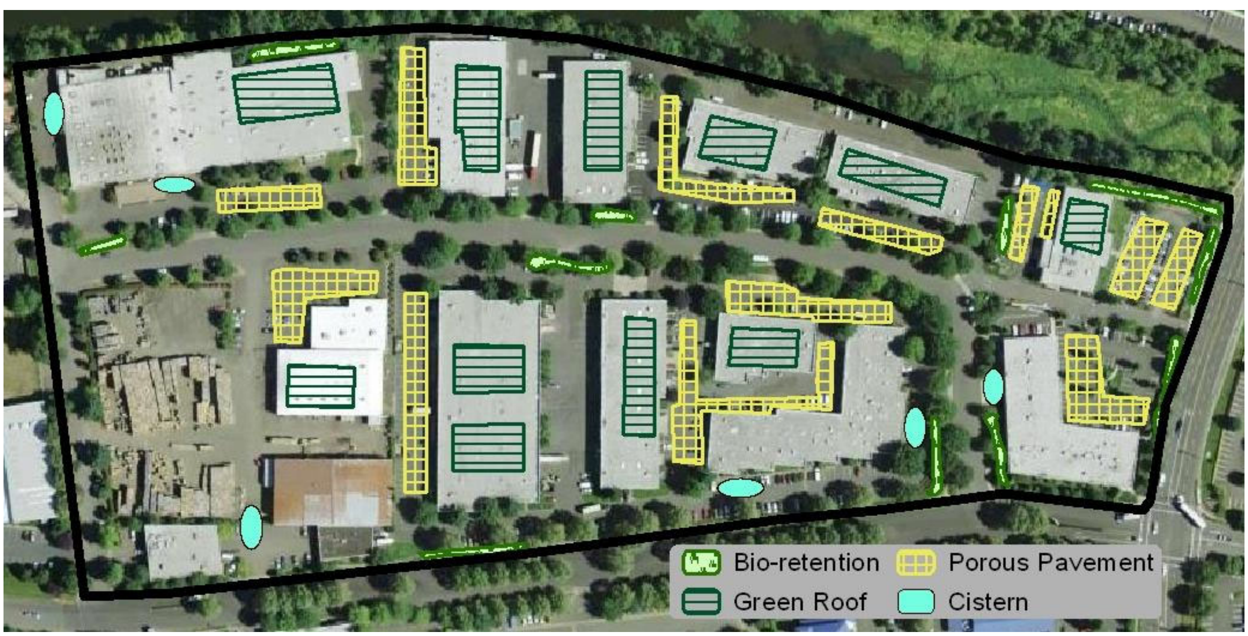


Figure 3A3-6. Actual site and onsite control measures (Portland, OR).

Table 3A3-9. Estimated sizes of on-site control measures for Scenario #4 (Portland, OR)

Total Area (acres)		27	
Estimated Imperviousness (%)		95%	
95th percentile Rainfall Event (inches)		1.00	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.86	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Paver block area estimated by Direct Determination (acres)		1.4	3.5*
Bioretention estimated by Direct Determination (acres)		0.4	
Green Roof estimated by Direct Determination (acres)		1.7	
Cistern volume estimated by Direct Determination (gallons)		50,000	
Off-site storage necessary to control the 10-yr event of 3.7 inches (acre-ft)	With on-site controls	5.37	5.62
	Without on-site controls	7.70	7.71

*The size of porous pavement area was increased because the other control options were maximized based on the site-specific design assumptions.

A total of 1.3 acres of the site is pervious area or landscaped of which, 0.4 acres (30 percent of the pervious area) could be converted to bioretention cells that have a storage depth of 10 inches. Of the 8.8 acres of current rooftop area, 1.7 acres (20 percent of the rooftop area) could be retrofitted into green roof areas. Of the 16.9 acres of paved area, 1.4 acres (8 percent of the paved area) for hydrologic soil group B, or 3.5 acres (20 percent of the paved area) for hydrologic soil group C, of paver block systems could be implemented. One or more cisterns (as indicated in Figure 3A3-6) could be used to capture up to 50,000 gallons of runoff from rooftop areas. Note: The high percentage of imperviousness of the site (95 percent) requires that all infiltration designs be based on resident soil type and design volumes, or with adequate sub-bases or amended soils.

Scenario #5 – Near Phoenix, Arizona

A 2-acre site with 47 percent impervious area was selected near Phoenix, Arizona (Figure 3A3-7). If the 95th percentile rainfall event (1.0 inch) occurred on the existing site (i.e., with no control measures), 0.42 inch of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.06 acre if the hydrologic soil group B is present or 0.1 acre if hydrologic soil group C (Table 3A3-10) is the predominant soil type on the site. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 1.1 acres of pervious area is available for the placement of these practices. The design storage depth of media within the designated bioretention area was 6 inches. Note: If the design storage depth were increased to 10 inches, the off-site storage necessary for the 10-year event could be reduced to 0.03 acre-ft for type B soils and 0.08 acre-ft for type C soils.

Figure 3A3-7. Actual site and on-site control measures (Phoenix, AZ).

Table 3A3-10. Estimated sizes of on-site control measures for Scenario #5 (Phoenix, AZ)

Total Area (acres)		2	
Estimated Imperviousness (%)		47%	
95th Percentile Rainfall Event (inches)		1.00	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.42	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination (acres)		0.06	0.1
Off-site storage necessary to control the 10-yr event of 2.4 inches (acre-ft)	With on-site controls	0.05	0.12
	Without on-site controls	0.18	0.18

Scenario #6 – Boston, Massachusetts

A 3.5-acre site with 69 percent impervious area was selected in Boston, Massachusetts (Figure 3A3-8). If the 95th percentile rainfall event (1.52 inches) occurred on the existing site (i.e., with no control measures), 0.98 inch of runoff would be generated and require management. Given these site characteristics, there is adequate area to place appropriately sized bioretention cells to capture the 95th percentile storm event. However, for the purposes of this analysis, unspecified conditions preclude the use of bioretention. As a result, a paver block system was selected as the best on-site control measure, and the system was designed such that the necessary design parameters could be achieved by storing some of the volume in the paver media and by infiltrating the remainder of the volume. The runoff from the 95th percentile rainfall event could be retained by installing a paver block area totaling 0.4 and 0.8 acre assuming soil types B and C, respectively (Table 3A3-11). For the purposes of this case study, a total of 1.5 acres of parking lot was made available to accommodate the paver block system. The area retrofitted with paver blocks would primarily be dedicated for use as parking stalls.

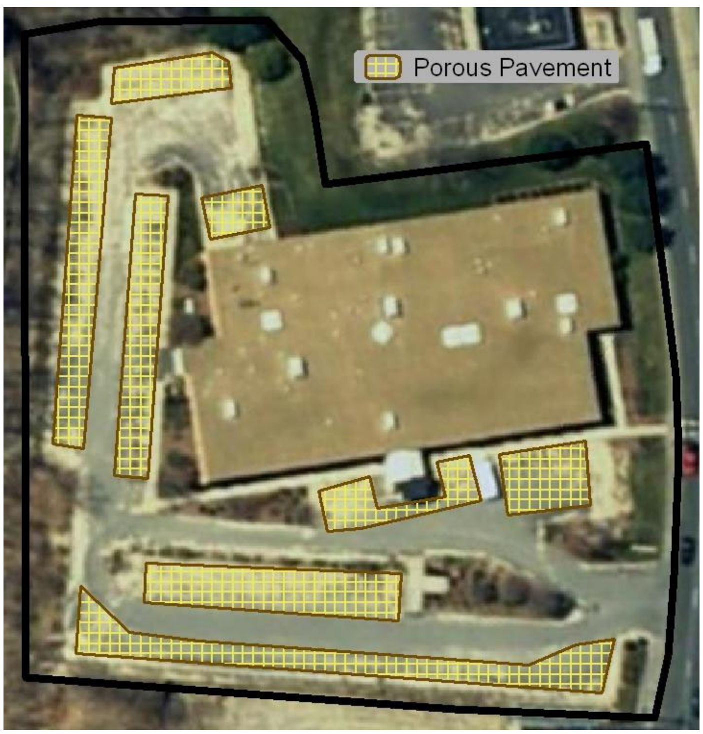


Figure 3A3-8. Actual site and on-site control measures (Boston, MA).

Table 3A3-11. Estimated sizes of on-site control measures for Scenario #6 (Boston, MA)

Total Area (acres)		3.5	
Estimated Imperviousness (%)		69%	
95th Percentile Rainfall Event (inches)		1.52	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.98	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Paver block area estimated by Direct Determination (acres)		0.4	0.8
Off-site storage necessary to control 10-yr event of 4.5 inches (acre-ft)	With on-site controls	0.59	0.71
	Without on-site controls	0.89	0.96

Scenario #7 – Atlanta, Georgia

A 21-acre site with 70 percent impervious area was selected in Atlanta, Georgia (Figure 3A3-9). If the 95th percentile rainfall event (1.77 inches) occurred on the existing site (i.e., with no control measures), 1.17 inches of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could not be adequately retained solely with bioretention systems. Because of the technical considerations of constructing and maintaining control measures at the site, it was assumed that up to 15 percent of the pervious area could be converted into bioretention cells, and up to 40 percent of paved area could be converted into a paver block system. If the stormwater management techniques used on the site include both bioretention and paver blocks as presented in Table 3A3-12, all runoff for the 95th percentile rainfall event would be controlled.

Figure 3A3-9. Actual site and on-site control measures (Atlanta, GA).

Table 3A3-12. Estimated sizes of on-site control measures for Scenario #7 (Atlanta, GA)

Total Area (acres)		21	
Estimated Imperviousness (%)		70%	
95^{th} Percentile Rainfall Event (inches)		1.77	
Expected Runoff for the 95^{th} Percentile Rainfall Event (inches)		1.17	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination (acres)		0.9	
Paver block area estimated by the Direct Determination (acres)		0.9	3.2*
Bioretention estimated by TR-55		0.8**	0.9
Paver block area estimated by TR-55		0**	1.84
Off-site storage necessary to control 10-yr event of 6.0 inches (acre-ft)	With on-site controls	5.85	6.62
	Without on-site controls	7.25	8.49

*The size of porous pavement was increased because the bioretention already reached its maximum size based on the site-specific design assumptions.

**Because TR-55 estimated smaller runoff in this scenario, bioretention can retain all of the 95^{th} percentile runoff if the site has soil group B.

For the example site in Atlanta, Georgia, areas of 1.8 acres for hydrologic soil group B, and 4.1 acres for hydrologic soil group C, would be required to manage the runoff discharged from a 95^{th} percentile rainfall event. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 6.2 acres of pervious area is available for placing bioretention systems. The design storage depth of media within the designated bioretention area was 10 inches. Permeable pavement systems could be used to treat the remaining volume on the 10.8 acres of existing paved area.

In applying the TR-55 model, the overall curve numbers for the site were 87 and 91 for Group B and C soils, respectively. TR-55 was used to estimate 0.73 inch of runoff for soil group B and 0.97 inch for soil group C, which are smaller numbers than the 1.17 inches of runoff estimated by the Direct Determination method. As a result, the sizes of the on-site control measures designed using the TR-55 model were smaller than those designed using the Direct Determination method. Note: It is recommended that caution be exercised when using TR-55 to model storms less than 0.5 inch per event. See application of TR-55 in Table 3A3-4.

Cost estimates were also developed for this scenario (Table 3A3-13) to compare the costs to install on-site control measures to retain the 95^{th} percentile rainfall event, and costs to install traditional stormwater management controls (e.g., primarily curb and gutter with off-site retention). The cost estimates were developed for Hydrologic Soil Group B.

Table 3A3-13. Estimated costs for Scenario #7 (Atlanta, GA)

Sizes of on-site control practices			
		Controls for 95th Percentile Event	Traditional Stormwater Controls
Rainfall depth (in)		1.77	
Bioretention (acres)		0.94	
Paver blocks (acres)		0.86	
Off-site Pond	WQV (ac-ft)	--	1.75
	10-Yr Fld Cntr (ac-ft)	0.84	0.0
Total Off-Site Requirement (ac-ft)		0.84	1.75
Land Area (assumes avg 3 ft depth)		0.28	0.58
% of the site		8.5%	
Costs of on-site control practices			
Biorention/alternative		$232,923	$30,617
Paver block/alternative		$236,878	$88,409
Off-site Pond	WQV (ac-ft)	$0	$72,888
	10-Yr Fld Cntr (ac-ft)	$39,648	$0
Infrastructure	Pipe	$54,827	$191,095
	Inlet	$52,080	$79,360
Land Area (assumes $300K/acre)		$84,000	$175,000
Sum		**$700,356**	**$637,368**
% difference from Traditional		**9.9%**	

Scenario #8 – Cincinnati, Ohio

A 19-acre site with 51 percent impervious area was selected in Cincinnati, Ohio (Figure 3A3-10). If the 95th percentile rainfall event (1.45 inches) occurred on the existing site (i.e., with no control measures), 0.68 inch of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.8 acre if the hydrologic soil group B is present or 1.3 acres if hydrologic soil group C (Table 3A3-8) is the predominant soil type on the site. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 9.4 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 8 inches.

Scenario #8 represents an alternative to the Cincinnati, scenario in #3 (Figure 3A3-5). In this case, hydrologic soil group D was selected to represent the soil characteristics present for the entire site. Alternatively, simulations could have been run under the assumption that using infiltration practices were precluded by contaminated soils or high groundwater tables. Under those site conditions, bioretention options are severely limited and cannot be used to adequately capture the entire 95th percentile storm event. As a result, options such as cisterns and green roofs were considered. Without management practices, the 95th percentile rainfall event discharges 1.45 inches of stormwater, and 0.53 inch of this runoff is captured by on-site depression storage. The difference, 0.92 inch of runoff, would then require capture and management. Because of the technical considerations of constructing and maintaining controls at the site, it was assumed that up to 20 percent of pervious area can be converted into bioretention areas; up to 30 percent of paved area can be converted into porous pavement; and up to 30 percent of the rooftop area can be converted into green roofs. Cisterns can be added to the system if additional storage volume is required. Note that green roofs were selected lowest in the hierarchy of practices evaluated because of cost and potential structural issues associated with design and placement on existing buildings. By using the four on-site control options as presented in Table 3A3-14, all runoff for the 95th percentile rainfall event would be retained. From a management perspective, it was assumed that the design storage depth within the designated bioretention area was 6 inches because of the low infiltration rates adopted for this scenario.

This site contains a total of 9.4 acres of pervious area, 8.0 acres of paved area, and 1.6 acres of rooftop area. If 1.9 acres (20 percent) of the pervious area were converted to bioretention cells; 2.4 acres (30 percent) of parking lot converted to paver blocks; and 0.5 acre (30 percent) of rooftop area were retrofitted to green roof areas for this site, 97 percent of stormwater runoff from the 95th percentile storm would be captured on-site. By also adding one or more cisterns (as indicated in Figure 3A3-10), an additional 13,000 gallons could be captured, thus illustrating that 100 percent of the rainfall from the 95th percentile event can be managed on-site with GI/LID practices.

Figure 3A3-10. Actual site and on-site control measures (Cincinnati, OH).

Table 3A3-14. Estimated sizes of on-site control measures for Scenario #8 (Cincinnati, OH)

Total Area (acres)	19
Estimated Imperviousness (%)	51%
95th Percentile Rainfall Event (inches)	1.45
Expected Runoff for the 95th Percentile Rainfall Event (inches)	0.92
Stormwater Management Applied	Hydrologic Soil Group D
Bioretention estimated by Direct Determination (acres)	1.9
Paver block area estimated by Direct Determination (acres)	2.4
Green Roof estimated by Direct Determination (acres)	0.5
Cisterns estimated by Direct Determination (gallons)	13,000

Scenario #9 – Norfolk, Virginia

A 1.6-acre site with 91 percent impervious area was selected from Norfolk, Virginia. Table 3A3-15 contains the land use categories for the site. Figures 3A3-11 and 3A3-12 depicts the site and associated facilities. Site-specific factors based on an METF analysis allow management of 75 percent of the 95th percentile storm on-site (1.27 inches). The remaining portion of the 95th percentile rainfall event (0.41 inch would be discharged off of the site.

Table 3A3-15. Land use determination after redevelopment

Land use	Acres	Site coverage percent
Building	0.90	56.3
Parking	0.35	21.9
Streets/Sidewalks	0.20	12.5
Undeveloped	0.15	9.3
Total	**1.60**	**100%**

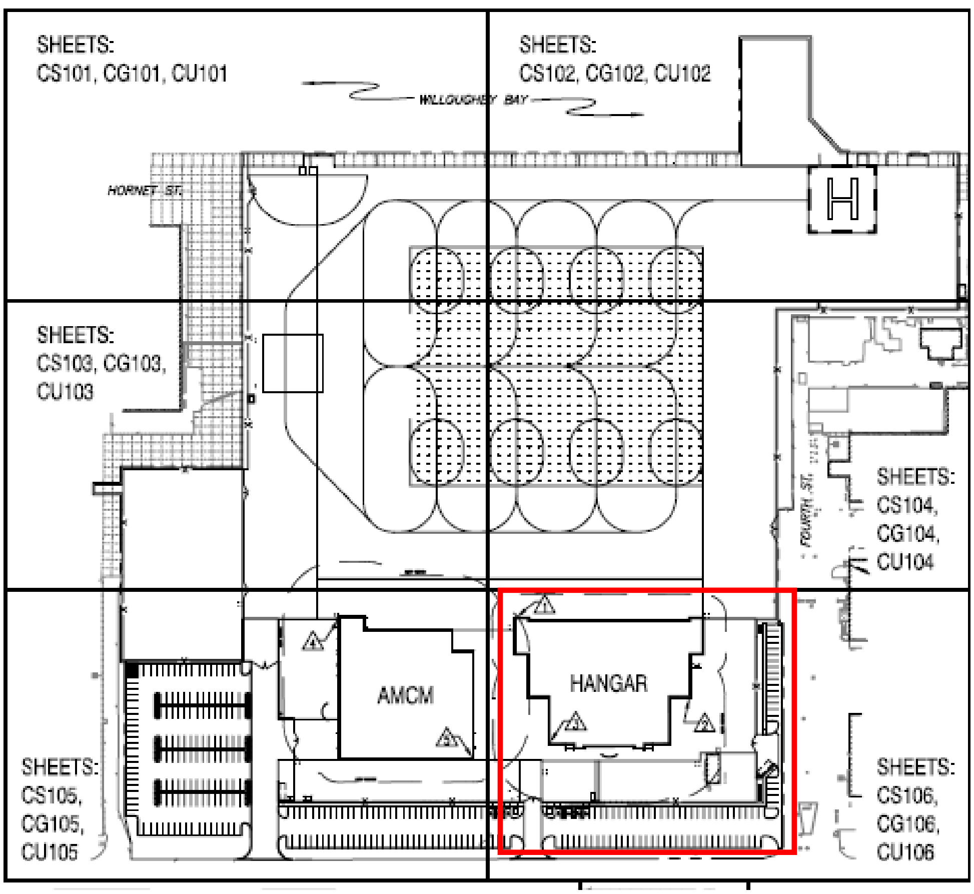


Figure 3A3-11. Proposed redevelopment scenario.

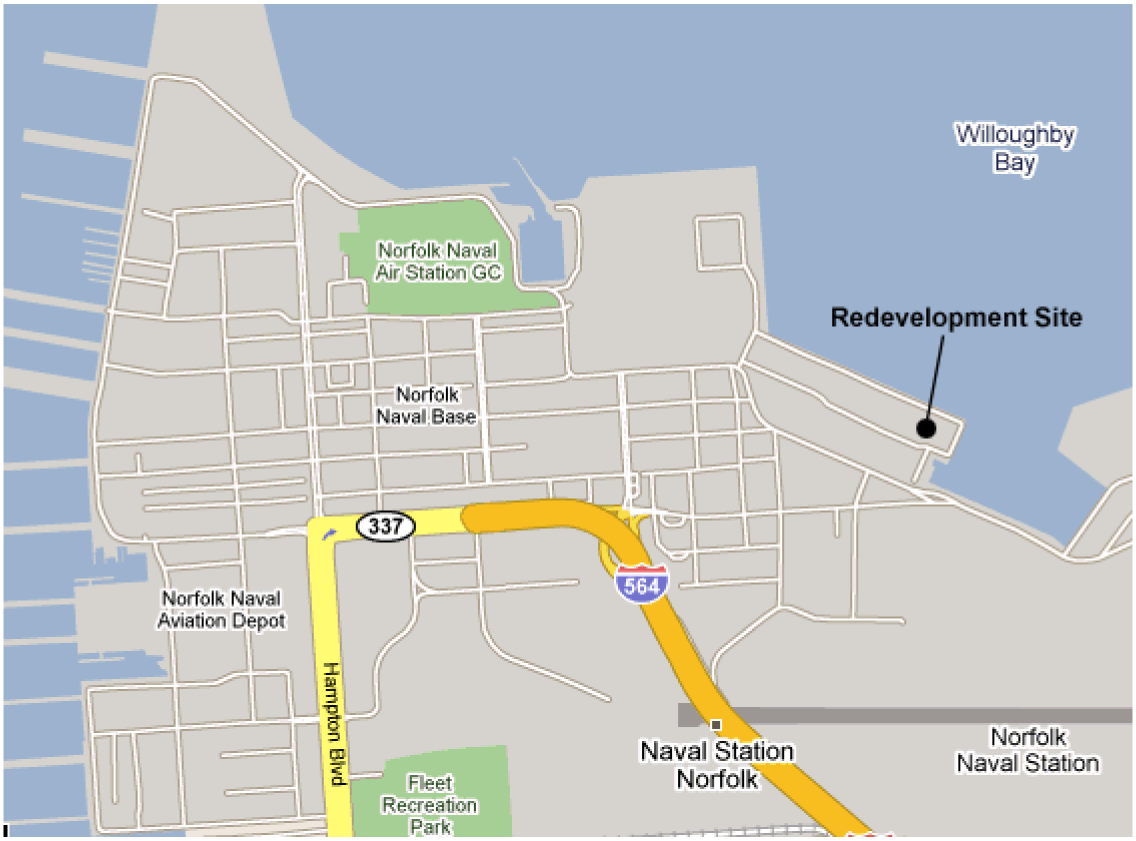


Figure 3A3-12. Location of facility (Norfolk, VA).

Site conditions and intended uses limited the number of practices that were technically feasible to use on-site to manage runoff. For example, a green roof was not feasible because the project includes the construction of an airplane hanger that lacks the structural strength to support a green roof. Cisterns were also not included in the set of suitable practices analyzed, which considered the number of people and amount of daily water use at the site, i.e., 40 people x 3.5 toilet flushes per day would use only 280 gallons of runoff per day or 2,000 gallons per week. Stormwater use for HVAC make-up would also be negligible according to the typical cooling system design. To put things in perspective, if the hanger rooftop covers the entire building footprint, 41,000 gallons of runoff would be generated from a 1.68-inch rainfall. Assuming a drawdown of 2,000 gallons per week from toilet flushing, the users would use only 5 percent of the 95th percentile event. Because of the relatively large volume of water that would need to be collected and used, cisterns were not considered a feasible option to manage a significant volume of runoff at the site.

However, site conditions did allow for both permeable pavement and bioretention practices (Figure 3A3-13 and Table 3A3-16). Approximately 0.15 acre (6,500 sf) of the proposed site is undeveloped and available for bioretention. On the basis of Department of Defense facility requirements, 10 percent of the parking area is designed with landscaping, usually around the perimeter and in landscaped islands. If the 10 percent were designed as bioretention cells, 0.035 acre of bioretention would be achieved. If bioretention cells were also placed in about 30 percent of the undeveloped area of the project, an additional 0.045 acre of bioretention could be implemented. Note: not all undeveloped land was assumed to be available for bioretention because of conflicts with site utilities, security and antiterrorism requirements and slopes that limited the use of infiltration practices directly adjacent to the hanger.

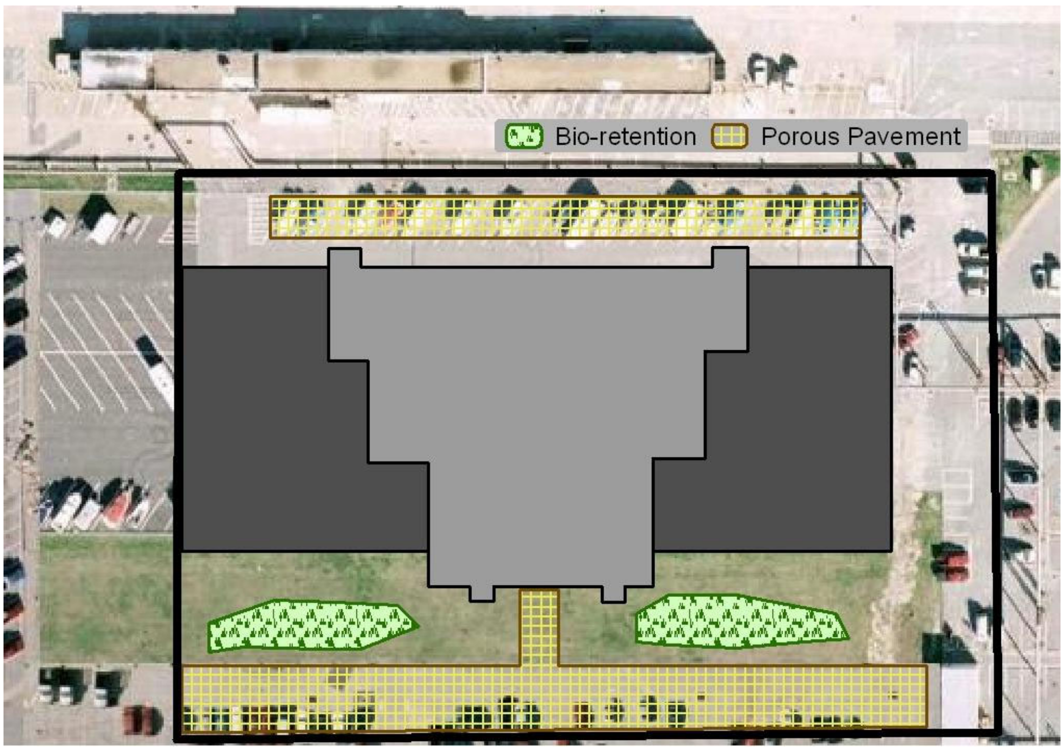


Figure 3A3-13. Actual site and on-site control measures (Norfolk, VA).

Table 3A3-16. Estimated sizes of on-site control measures for Scenario #9 (Norfolk, VA)

Total Area (acres)	1.6
Estimated Imperviousness (%)	91%
95th Percentile Rainfall Event (inches)	1.68
Expected Runoff for the 95th Percentile Rainfall Event (inches)	1.50
Stormwater Management Area Required	Hydrologic Soil Group D
Porous Pavement estimated by Direct Determination method (acres)	0.21
Bioretention estimated by Direct Determination method (acres)	0.08

The bioretention cells were designed with an effective storage depth of 10 inches, which includes a depth from media surface to outlet of 10 inches. In this case study, state regulations precluded the project from taking credit for the storage potential provided by the void space within the bioretention cell media. Similarly, approximately 0.55 acre of the proposed site is impervious because of parking lots, streets, and sidewalks. Because of the manufacturer's recommendation that permeable pavement materials not be used in applications subject to heavy loads and potential pollutant exposure, the access roads and parking lot access isles were assumed to be constructed from conventional impervious concrete or asphalt. Thus, 60 percent of the parking area (primarily parking stalls and sidewalks), which is about 38 percent of the entire paved area, is assumed to be suitable for paver blocks. A high water table at the site limited the modeled net storage depth under paver blocks in the parking areas and sidewalks to 4 inches. This storage was calculated using the assumption that the pavement sub-base of 12 inches would have a minimum void space of approximately 30 percent.

Comparison of the Runoff Estimation Methods

As illustrated in each of the case studies above, runoff of the 95th percentile storm was estimated to size on-site control measures. The estimates were produced by applying four different methods: the Direct Determination method, the Rational Method, the NRCS TR-55, and the EPA SWMM. The results comparing each of the methods for scenarios 1 through 7 are presented in Tables 3A3-17 and 3A3-18.

Table 3A3-17. Comparison of the estimated runoff (unit: inches)

Method		**Direct determination**		**Rational method**		**TR-55**		**SWMM**	
Soil Groups		B	C	B	C	B	C	B	C
1	Charleston, WV	0.82	0.82	0.83	0.84	0.36	0.53	0.82	0.83
2	Denver, CO	0.53	0.53	0.57	0.59	0.12	0.26	0.53	0.53
3	Cincinnati, OH	0.68	0.68	0.73	0.76	0.26	0.46		
4	Portland, OR	0.86	0.86	0.86	0.86	0.63	0.71		
5	Phoenix, AZ	0.42	0.42	0.46	0.48	0.06	0.17		
6	Boston, MA	0.98	0.98	0.99	1.00	0.51	0.70		
7	Atlanta, GA	1.17	1.17	1.17	1.19	0.73	0.97	1.19	1.23

As shown in the above table, the estimated runoff results from direct determination, the Rational method, and SWMM are relatively similar. Runoff volumes using TR-55 are lower than the other estimates. SWMM modeling results using NRCS 24-hour rainfall distributions were nearly identical to the results based on uniform distribution.

Table 3A3-18. Applicability of the methods for analyzing on-site control measures

Purpose	**Direct determination**	**Rational method**	**TR-55***	**SWMM**
Planning Tool	Applicable	Applicable	Applicable	Applicable
Preliminary Design	Applicable	Applicable	Applicable	Applicable
Detailed Design	Not applicable	Not applicable	Not applicable	Applicable
Actual Assessment (Long-term)	Not applicable	Not applicable	Not applicable	Applicable
Water Quality	Not applicable	Not applicable	Not applicable	Applicable

* Use with caution when applying this method for small storms

Conclusions

Although sites varied in terms of climate and soil conditions, in most of the scenarios selected, the 95th percentile storm event could be managed on-site with GI/LID systems. Other infiltration, evapotranspiration and capture and use stormwater management options are available in addition to those used in these analyses. These options provide site managers additional flexibility to choose appropriate systems and practices to manage site runoff.

References

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Resources: Runoff Methodology Parameter Assumptions

Runoff from each land cover was estimated by the following equation:

$$Runoff = Rainfall - Depression\ Storage - Infiltration\ Loss \qquad (1)$$

Depression Storage

Reference depression storage (inches)

Reference	Impervious	Pervious
1	0.05–0.1	0.1–0.3
2	0.01–0.11	0.02–0.6
3	0.1	0.2

1. ASCE. 1992. Design & Construction of Urban Stormwater Management Systems. New York, NY.

2. Marsaleck, J., B. Jimenez-Cisreros, M. Karamouz, P.R. Malmquist, J. Goldenfum, and B. Chocat. 2007. *Urban Water Cycle Processes and Interactions. Urban Water Series*, UNESCO-IHP, Tyler & Francis.

3. Walesh, S.G. 1989.*Urban Surface Water Management*. John Wiley & Sons, Inc.

On the basis of the above reference data, depression storage (or initial abstraction, the rainfall required for the initiation of runoff) to the direct determination method was assumed as follows:

- Rooftop: 0.1 inches
- Pavement: 0.1 inches
- Pervious area: 0.2 inches

Infiltration

Infiltration loss occurs only in pervious areas. In this analysis, infiltration was estimated by Horton's equation:

$$Ft = f_{min} + (f_{max} - f_{min})\ e - k\ t \qquad (2)$$

where

Ft = infiltration rate at time t (in/hr)
f_{min} = minimum or saturated infiltration rate (in/hr)
f_{max} = maximum or initial infiltration rate (in/hr)
k = infiltration rate decay factor (/hr)
t = time (hr) measured from time runoff first discharged into infiltration area

Reference infiltration parameters

Maximum infiltration rate (in.hr), f_{max}

Infiltration (in/hr)	Partially dried out with		Dry soils with	
	No vegetation	Dense vegetation	No vegetation	Dense vegetation
Sandy	2.5	5	5	10
Loam	1.5	3	3	6
Clay	0.5	1	1	2

Reference: Huber, W. C. and R. Dickinson. 1988. *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

Minimum infiltration rate (in/hr), f_{min}

Hydrologic Soil Group	Infiltration (in/hr)
A	0.45–0.30
B	0.30–0.15
C	0.15–0.05
D	0.05–0

A: well drained sandy; D: poorly drained clay

Reference: Huber, W.C., and R. Dickinson. 1988. *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

Decay coefficient, k

Soils	k (sec^{-1})	k (hr^{-1})
Sandy	0.00056	2
↕	0.00083	3
	0.00115	4
Clay	0.00139	5

Reference: Huber, W.C., and R. Dickinson. 1988. *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

On the basis of the above reference data, infiltration parameters to the direct determination method were assumed as follows:

- Hydrologic Soil Group B
  - Maximum infiltration rate: 5 in/hr
  - Minimum infiltration rate: 0.3 in/hr
  - Decay factor: 2 /hr

- Hydrologic Soil Group C
  - Maximum infiltration rate: 3 in/hr
  - Minimum infiltration rate: 0.1 in/hr
  - Decay factor: 3.5 /hr
- Hydrologic Soil Group D
  - Maximum infiltration rate: 1 in/hr
  - Minimum infiltration rate: 0.02 in/hr
  - Decay factor: 5 /hr

Infiltration loss for the 24-hour rainfall duration was estimated by the following equations with assumptions of a half hour Δt:

$$\textit{Infiltration Loss at the } n^{th} \textit{ time-step} = (f \times \Delta t) = \{(f_{n-1} + f_n)/2) \times \Delta t\} \quad (3)$$

$$\textit{Integrated Infiltration Loss for 24 hours} = \sum (f \times \Delta t) \quad (4)$$

Integrating infiltration loss during 24 hours with a half hour Δt

Time-step	t (hr)	Infiltration rate (in/hr)[a]			Infiltration volume (inches)[b]		
		Soil B	Soil C	Soil D	Soil B	Soil C	Soil D
0	0	5	3	1	0	0	0
1	0.5	2.03	0.60	0.100	1.757	0.901	0.275
2	1	0.94	0.19	0.027	0.741	0.198	0.032
3	1.5	0.53	0.12	0.021	0.368	0.076	0.012
4	2	0.39	0.10	0.02	0.230	0.054	0.01
5	2.5	0.33	0.1	0.02	0.179	0.05	0.01
6	3	0.31	0.1	0.02	0.161	0.05	0.01
7	3.5	0.30	0.1	0.02	0.154	0.05	0.01
8	4	0.3	0.1	0.02	0.15	0.05	0.01
9	4.5	0.3	0.1	0.02	0.15	0.05	0.01
10	5	0.3	0.1	0.02	0.15	0.05	0.01
11	5.5	0.3	0.1	0.02	0.15	0.05	0.01
12	6	0.3	0.1	0.02	0.15	0.05	0.01
13	6.5	0.3	0.1	0.02	0.15	0.05	0.01
14	7	0.3	0.1	0.02	0.15	0.05	0.01
15	7.5	0.3	0.1	0.02	0.15	0.05	0.01

Time-step	t (hr)	Infiltration rate (in/hr)[a]			Infiltration volume (inches)[b]		
		Soil B	Soil C	Soil D	Soil B	Soil C	Soil D
16	8	0.3	0.1	0.02	0.15	0.05	0.01
17	8.5	0.3	0.1	0.02	0.15	0.05	0.01
18	9	0.3	0.1	0.02	0.15	0.05	0.01
19	9.5	0.3	0.1	0.02	0.15	0.05	0.01
20	10	0.3	0.1	0.02	0.15	0.05	0.01
21	10.5	0.3	0.1	0.02	0.15	0.05	0.01
22	11	0.3	0.1	0.02	0.15	0.05	0.01
23	11.5	0.3	0.1	0.02	0.15	0.05	0.01
24	12	0.3	0.1	0.02	0.15	0.05	0.01
25	12.5	0.3	0.1	0.02	0.15	0.05	0.01
26	13	0.3	0.1	0.02	0.15	0.05	0.01
27	13.5	0.3	0.1	0.02	0.15	0.05	0.01
28	14	0.3	0.1	0.02	0.15	0.05	0.01
29	14.5	0.3	0.1	0.02	0.15	0.05	0.01
30	15	0.3	0.1	0.02	0.15	0.05	0.01
31	15.5	0.3	0.1	0.02	0.15	0.05	0.01
32	16	0.3	0.1	0.02	0.15	0.05	0.01
33	16.5	0.3	0.1	0.02	0.15	0.05	0.01
34	17	0.3	0.1	0.02	0.15	0.05	0.01
35	17.5	0.3	0.1	0.02	0.15	0.05	0.01
36	18	0.3	0.1	0.02	0.15	0.05	0.01
37	18.5	0.3	0.1	0.02	0.15	0.05	0.01
38	19	0.3	0.1	0.02	0.15	0.05	0.01
39	19.5	0.3	0.1	0.02	0.15	0.05	0.01
40	20	0.3	0.1	0.02	0.15	0.05	0.01
41	20.5	0.3	0.1	0.02	0.15	0.05	0.01
42	21	0.3	0.1	0.02	0.15	0.05	0.01
43	21.5	0.3	0.1	0.02	0.15	0.05	0.01
44	22	0.3	0.1	0.02	0.15	0.05	0.01
45	22.5	0.3	0.1	0.02	0.15	0.05	0.01
46	23	0.3	0.1	0.02	0.15	0.05	0.01
47	23.5	0.3	0.1	0.02	0.15	0.05	0.01
48	24	0.3	0.1	0.02	0.15	0.05	0.01
Sum: Infiltration loss during 24 hours[c]					9.743	3.430	0.769

[a] Calculated infiltration rate at each time by Equation (2)

[b] Calculated infiltration volume from the previous time to the current time by Equation (3)

[c] Integrated infiltration volume for 24 hours with a half hour Δt by Equation (4)

On the basis of the above calculation, 24-hour infiltration losses for pervious areas and bioretention areas were modeled as follows:

- Soil Group B: 9.743 inches
- Soil Group C: 4.430 inches
- Soil Group D: 0.769 inches

Infiltrations of underlying soils at paver blocks were modeled conservatively by applying the minimum infiltration rate for each soil type (Infiltration loss = f_{min} × 24) because the soils under the paver blocks could require or be subjected to some compaction for engineering stability. The estimated infiltration losses for each soil are presented below:

- Soil Group B: (0.3 in/hr) × (24 hrs) = 7.2 inches
- Soil Group C: (0.1 in/hr) × (24 hrs) = 2.4 inches
- Soil Group D: (0.02 in/hr) × (24 hrs) = 0.48 inches

Design Storage of Management Practices

Bioretention

Reference	Ponding (inches)[1]	Mulch (inches)	Soil media (ft)	Soil media porosity	Underdrain
1	up to 12	2–4 (optional)	1–1.5	about 40%	bioretention systems utilize infiltration rather than an underdrain
2	6–12	2–3	2.5–4	about 40%	recommended, especially if initial testing infiltration rate < 0.52 in/hr
3	6–12		2–4		
4		2–3	1.5–4		if necessary
5	up to 6		1.5–2	30%–40%	Optional
6	6–18	as needed	2–4		if necessary

1. State of New Jersey. 2004. *New Jersey Stormwater Best Management Practices Manual* www.nj.gov/dep/stormwater/tier_A/pdf/NJ_SWBMP_9.1 print.pdf.

2. MDE (Maryland Department of the Environment). 2000. *2000 Maryland Stormwater Design Manual, Volumes I & II*, prepared by the Center for Watershed Protection and the Maryland Department of the Environment, Water Management Administration, Baltimore, MD. www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp.

3. Clar, M.L., and R. Green. 1993. *Design Manual for Use of Bioretention in Storm Water Management*, prepared for the Department of Environmental Resources, Watershed Protection Branch, Prince George's County, MD, by Engineering Technologies Associates, Inc. Ellicott City, MD, and Biohabitats, Inc., Towson, MD.

4. USEPA (U.S. Environmental Protection Agency). 1999. *Storm Water Technology Fact Sheet: Bioretention*. EPA 832-F-99-012. Office of Water. US Environmental Protection Agency. Washington, D.C. www.epa.gov/owm/mtb/biortn.pdf.

[1] Ponding is a measure of retention capacity

5. Prince George's County. *Bioretention Design Specifications and Criteria*. Prince George's County, MD. www.co.pg.md.us/Government/AgencyIndex/DER/ESG/Bioretention/pdf/bioretention_design_manual.pdf.

6. City of Indianapolis. 2008. *Indianapolis Stormwater Design Manual*. www.sustainindy.org/assets/uploads/4_05_Bioretention.pdf.

Paver Blocks

Reference	Media (inches)	Void space
1	12 or more	40%
2	9 or more	40%
3	12–36	40%

1. University of California at Davis. 2008. *Low Impact Development Techniques: Pervious Pavement*. http://extension.ucdavis.edu/unit/center_for_water_and_land_use/pervious_pavement.asp.

2. AMEC Earth and Environmental, Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, and Atlanta Regional Commission. 2001. Georgia Stormwater Management Manual Volume 2: Technical Handbook www.georgiastormwater.com/.

3. Subsurface Infiltration Bed. www.tredyffrin.org/pdf/publicworks/CH2 - BMP4 Infiltration Bed.pdf.

Green Roofs

Reference	Media (inches)
1	3–4
2	1–6
3	2–6

1. Charlie Miller. 2008. Extensive Green Roofs. Whole Building Design Guide (WBDG). www.wbdg.org/resources/greenroofs.php.

2. Great Lakes WATER Institute. Green Roof Project: Green Roof Installation. www.glwi.uwm.edu/research/genomics/ecoli/greenroof/roofinstall.php.

3. Paladino & Company. 2004. Green Roof Feasibility Review. King County Office Project. http://your.kingcounty.gov/solidwaste/greenbuilding/documents/KCGreenRoofStudy_Final.pdf.

On the basis of the above reference data, design storages to the direct determination method were assumed as follows:

- Bioretention: up to 10 inches (depending on practice used, site conditions, and the like)
- Green roof: 1 inch (2.5 inches deep media with 40 percent void space)
- Porous pavement: 4 inches (10 inches deep media with 40 percent void space)

Factors that influence total storage available include, ponding depth, available media void space, and supplemental storage if the system is designed with gravel or open pipes underneath the media.