# Chapter 4
# Best Management Practices Design

## Introduction

This chapter provides detailed information for best management practices (BMPs) commonly used for the control of erosion and sediment on active construction sites. Practices for stormwater control will be installed in accordance with an approved site plan. (Reference Chapter 3, of both Volume 1 and Volume 2, for guidance on developing the erosion- and sediment-control plans and the Stormwater Pollution Prevention Plan. Appendix D provides examples of such plans.) The plan should list the sequence of construction activities. Each construction activity contributing to erosion of soil or changes in sediment-laden runoff should have an appropriate practice or practices to control erosion, sediment, and runoff. Minimizing the area exposed to erosion at any one time can significantly reduce erosion and sediment occurrence on the site.

Proper installation and maintenance of structural and vegetative practices approved in the site plan will be considered essential for compliance with the plan or associated permit. This chapter includes practice design standards and construction specifications along with applicable drawings. Design limitations are provided to maintain design integrity, safety, and purpose of the practices.

## Purpose of BMP Manual

The purpose of this manual is to assist designers, developers, owners, contractors, and local officials in determining what stormwater regulations apply to their situation, what the BMP to meet those regulations might be, and how to then design and maintain that particular erosion and sediment control BMP. It is intended to provide the competent design professional with the information necessary both to properly meet the minimum requirements of Mississippi's stormwater programs and to be able to design a stormwater BMP that meets the water quality objectives. However, it does not cover every aspect of the civil engineering and structural design necessary for proper BMP system design and construction, nor does it cover every site situation that may occur, or every possible erosion and sediment control solution. The design professional is responsible for the design and construction of a properly functioning BMP that meets all of the applicable regulations, including the water quality objectives, and that considers all the unique conditions of an individual site. Where the designer determines that conformance with this manual would create an unreasonable hardship or where an alternative design may be more appropriate, alternative designs, materials, and methodologies will be considered on a case-by-case basis.

This manual is meant to supplement (not supplant) Mississippi's stormwater regulations by explaining the BMPs that will be allowed and their design criteria, in an easy-to-understand manner. In addition, local communities are free to adopt more stringent requirements than those presented in this manual. In general, if any part of this manual lists requirements different from those imposed by any other ordinance, rule, regulation, or other provision of law, whichever provision is more restrictive or imposes higher protective standards for human or environmental health, safety, and welfare shall control.

Figures, example calculations, operation and maintenance items, etc., are used throughout this manual. The intention is to provide the reader with visual assistance in device functions, siting, and concepts, as well as guidance on designing, operating, and maintaining specific BMPs. The figures, example calculations, operation and maintenance items, etc., will not represent the proper solution for every situation, and they may contain items that do not exactly fit the requirements listed in the section. The user of this manual must look at these items and use his or her professional judgment as to their proper use in a specific situation (however, any variance from a requirement must be clearly indicated). In the event of a conflict or inconsistency between the text of this manual and any heading, caption, figure, illustration, table, map, etc., the text shall control.

Also used throughout this manual is the phrase “design professional.” This phrase is a generic title for a qualified, registered, Mississippi professional engineer, surveyor, soil scientist, or landscape architect, performing services only in his or her area of competence. Other individuals may be authorized as a “design professional,” if they can demonstrate proper knowledge and ability to the Mississippi Department of Environmental Quality.

# Conservation Easements

## Practice Description

Conservation easements are voluntary agreements that allow individuals or groups to limit the type or amount of development on their property. A conservation easement can cover all or just a portion of a property and it can be either permanent or temporary. Easements typically describe the resource they are designed to protect (e.g., agricultural, forest, historic, or open space easements), and they explain and mandate the restrictions on the uses of the particular property. Easements can relieve property owners of the burden of managing these areas. They do so by shifting responsibility to a private organization, such as a land trust or government agency, that is better equipped to handle maintenance and monitoring issues. In some cases, tax benefits might be realized by property owners who place conservation easements on some or all of their property.

Conservation easements may indirectly contribute to water quality protection. Land set aside in a permanent conservation easement has a prescribed set of uses or activities that generally restrict future development. The location of the land held in a conservation easement should be evaluated to determine its ability to provide water quality benefits. Property along stream corridors and shorelines can act as a vegetated buffer that filters out pollutants from stormwater runoff. The ability of a conservation easement to function as a stream buffer depends on the width of the easement and in what vegetated state the easement is maintained. Easements may also be used to provide tax benefits for other desirable practices, like tree and natural areas conservation (Center for Watershed Protection (CWP), 1998).

## Planning Considerations

Conservation easements are designed to ensure that the land is preserved in its current state long after the original owners no longer control the property. By agreeing to give up or restrict development rights for a parcel of land, landowners can guarantee their property will remain in a prescribed state for perpetuity while receiving tax benefits.

Conservation easements have been used in all parts of the country, and many private groups (on both the national and local levels) exist to preserve natural lands and to manage the conservation easements. States also use conservation easements and land purchase programs to protect significant environmental features and tracts of open space.

Regardless of whether a conservation easement is held by a government agency or a private land trust, certain management responsibilities must be addressed by the easement holder. The following is a list of some of these management duties:

- Ensure that the easement's language is clear and enforceable.
- Develop maps, descriptions and baseline documentation of the property's characteristics.
- Monitor the use of the land on a regular basis.
- Provide information about the easement to new or prospective property owners.
- Establish review and approval processes for land activities stipulated in the easement.
- Enforce the easement's restrictions through the legal system, if necessary.
- Maintain property/easement-related records.

## Design Criteria

Often, state agencies and private land trusts have specific qualifications for a property before they will enter into an easement agreement with landowners. Table 1 contains examples of criteria used by private land trusts to determine if a property is worth managing in a conservation easement.

**Table 1 Typical criteria that land trusts use to determine feasibility of entering into conservation easement agreement**

| Criteria | Details |
|---|---|
| Natural resource value | Does the property provide a critical habitat or important environmental aspects worth preserving? |
| Uniqueness of the property | Does the property have unique traits worth preserving? |
| Size of land | Is the land large enough to have a natural resource or conservation value? |
| Financial considerations | Are funds available to meet all financial obligations? |
| Perpetuity | Is the conservation agreement a perpetual one? |
| Land trust's mission | Does the property align with the land trust's mission and the organization's specific criteria? |

Maryland has been nationally recognized for its programs that provide funding for state and local parks and conservation areas. The state is one of the first to use real estate transfer taxes to pay for land conservation programs. Several programs are funded through this transfer tax of one-half of one percent ($5 per thousand) of the purchase price of a home or land, or other state funding programs. Conservation programs include these:

*Program Open Space*. This program is responsible for acquiring 150,000 acres of open space for state parks and natural resource areas, and more than 25,000 acres of local park land. Every county must create a Land Preservation and Recreation Plan that outlines acquisition and development goals in order to receive a portion of the 50 percent that is granted to local governments (USEPA, 2006b).

*Maryland Environmental Trust*. This trust is a state-funded agency that helps citizen groups form and operate local land trusts. It offers the land trusts technical assistance, training, grants for land protection projects and administrative expenses, and participation in the Maryland Land Trust Alliance (MNDR, 2001a).

*Rural Legacy Program*. This is a Smart Growth Initiative that redirects existing state funds into a focused and dedicated land preservation program specifically designed to limit the adverse effects of sprawl on agricultural lands and natural resources. The program purchases conservation easements for large contiguous tracts of agricultural, forest, and natural areas subject to development pressure, and purchases fee interests in open space where public access and use are needed (MNDR, 2001b).

## Maintenance

A conservation area's pollutant removal efficiency depends on how much land is conserved, the techniques used to conserve it, and the specific nature of the easement. Conservation easements are assumed to contribute water quality benefits, but no national studies proving this have been released.

**Table 2 Annual maintenance costs of different types of green space uses (CWP, 1998)**

| Land Use | Approximate Annual Maintenance Costs |
|---|---|
| Natural open space<br>Only minimum maintenance, trash/debris cleanup | $75/acre/year |
| Lawns<br>Regular mowing | $270 to $240/acre/year |
| Passive recreation | $200/acre/year |

# Development Districts


## Practice Description

Development districts, often referred to as special zoning districts, are created for the purpose of permitting property development. Development districts are characterized by larger site areas (typically 5 or more acres), and their construction requires complex and coordinated rezoning, transportation, and planning efforts. Examples of special zoning districts include, but are not limited to, the following:

- Transit Oriented Development districts,
- Business Improvement Districts,
- Traditional Neighborhood Designs,
- Brownfields Redevelopment Projects, and
- Main Street Revitalization Districts.

A development district's stormwater handling performance is typically assessed at the site, neighborhood, regional or watershed levels. While the construction of a development district may involve a higher percentage of imperviousness than surrounding or conventional patterns, satisfying development needs on a smaller footprint brings benefits. In addition, the coordinated planning effort can help identify strategic opportunities for infiltration, stormwater recapture, and treatment.

## Planning Considerations

A city, county or town's Planning or Zoning Department usually develops plans for development districts. Stormwater managers may need to meet with planning counterparts to coordinate plans, since the common, stand-alone elements found in stormwater management plans for individual sites (such as site coverage limitations, infiltration requirements, and rules discouraging sidewalks) can run counter to the urban design elements of successful development districts.

A development district's effectiveness can be viewed at the site, neighborhood, and watershed levels. Redevelopment can significantly reduce the demand for new development elsewhere in the watershed. Designs that repair existing infrastructure and treat stormwater on-site are particularly beneficial. Where urban redevelopment occurs on open lots that serve a stormwater handling function, the city and developer will need to assess the impacts neighborhood-wide and mitigate accordingly.

Clustering, open space, and other "green" designs offer stormwater and water quality benefits to communities considering new housing developments. However, the site's design needs to be combined with watershed and regional planning designs that curb uncontrolled, large-scale growth. It is important to consider neighborhood and watershed outcomes. Will new conservation development spur unplanned development? Does conservation development complement the community's overall conservation goals? How does the new development relate to jobs, schools, and services?

The costs of developing and implementing coordinated development districts vary. The primary drivers of these costs are consultant and staff time to develop or align plans; repair or establishment of water, sewer, and transportation infrastructure; and any incentives a city, county, or township provides to developers or public/private partnerships. For developers, costs can vary from a conventional site plan, dependent upon the combinations of BMPs and the relative cost of a more complex site development plan. However, many redevelopment projects command a premium market price due to their location or enhanced desirability.

## Design Criteria

Development districts can be incorporated anywhere. One main consideration for rural areas might be a lack of zoning or other land use classification. Subdivision regulations or drainage district requirements may impede plans to establish a mix of uses or higher densities. For urban areas, look for designs that reuse existing impervious surface and infrastructure and provide opportunities to repair infrastructure or handle stormwater on-site. For conservation subdivisions or designs, look closely at the connections among transportation, community services, and jobs. The water quality benefits of conservation clustering can be negated if the new housing becomes part of a development pattern that includes dispersed uses, demands for upgrades to urban-level services and transportation, and a lack of connections among infrastructure elements.

### Compact Project and Community Design

Compact project and community design is a powerful strategy for reducing a development's footprint and, hence, its stormwater impact. Reducing an individual building's footprint is another strategy, though there are circumstances that call for greater lot coverage in districts where higher development intensity is needed (near transit stations, for example). Compact development also lends itself to more environmentally friendly transportation options, such as walking and biking, or shorter and less frequent automobile trips.

### Street Design and Transportation Options

Well-designed, compact communities are served by a highly connected street and trail system designed for multiple modes of transportation. The pattern need not be a grid; in some areas, topography and environmentally sensitive areas will influence where roads go. A compact district also provides for more efficient use and reuse of infrastructure.

### Mix of Uses

A community's transportation options increase when jobs, housing, and commercial activities are located close together. Efficiencies for providing infrastructure also emerge. Fewer auto trips reduce the need to accommodate standard parking requirements. Mixing daytime and nighttime uses increases the opportunities for businesses to share parking spaces.

### Regional Applicability

Development districts can be large redevelopment efforts, infill projects, or new "greenfields" projects. The regional applicability is strong since successful development districts coordinate multiple objectives, including environmental protection and stormwater control. These districts also tend to handle more development intensity and a mix of uses on a smaller footprint; Thus, they also have applicability for watershed planning and source water protection.

#### *Ultra-Urban Applicability*

Although land constraints and large developable sites can be a challenge, certain types of development district planning, such as transit oriented development and business improvement districts, are common in urban areas.

Urban development and redevelopment projects are more likely to be served by heavier transit, follow a traditional street pattern, and be governed by a complex set of existing land development requirements. Municipalities can use a combination of policies to promote desired densities. Some of these policies include the following:

- Transfer of development rights receiving zones – A system in which a landowner in a "preservation area" or "sending zone" gets credits for forgoing development rights that he can sell or have a "bank" consolidate. Developers can buy and use these credits to gain permission for denser development in "receiving zones," which are areas targeted for denser development,

- Bonus densities – which permit developers who agree to complete projects or project additions that meet specific goals to increase density,

- Create mixed-use zoning,
- Create form-based zoning codes,
- Modify parking policies that, for example, create a maximum number of parking spaces allowed and have better management of on-street parking,
- Create sidewalk improvement programs,
- Encourage micro-detention stormwater handling areas such as use of rain gardens or stormwater BMPs that serve multiple purposes (i.e., green roofs),
- Encourage street tree canopy programs,
- Create financial incentives (tax-increment financing, vacant property reform),
- Enact or promote programs to enhance transit use,
- Enact rehabilitation codes for older buildings using proprietary devices (e.g., in-pipe filtration devices).

#### *Suburban Settings*

Suburban development districts are likely to take advantage of existing development and infrastructure, and require connections among older developed areas. In addition to some of the policies in urban settings, planners and developers in suburban settings could consider the following BMPs and policies to aid in protecting water resources:

- Promote Grayfields programs to redevelop underperforming malls and strip malls,
- Create highway corridor redevelopment programs,
- Enhance retail and housing districts around park and ride lots,
- Adopt Smart Growth street design standards at local and state levels,
- Establish infill policies,
- Adopt traditional neighborhood design manuals that integrate transportation.

#### *Rural Settings*

Rural development districts are likely to occur on undeveloped or sparsely developed land. Successful rural development districts will complement or spur rural employment opportunities, such as agriculture, manufacturing, or warehousing and distribution. To protect water resources on a regional scale, planners should encourage conservation of rural settings to offset increased impervious areas in urban and suburban settings.

Policies that encourage economic development while retaining rural character include:

- Create transfer of development rights sending zones,
- Establish water protection overlay zones,
- Connect housing with rural job and transportation centers,

- Create watershed-wide impervious surface trading programs,
- Create design manuals for rural housing or housing in environmentally sensitive areas,
- Encourage “Main Street” redevelopment programs in older downtowns.

## Common Problems

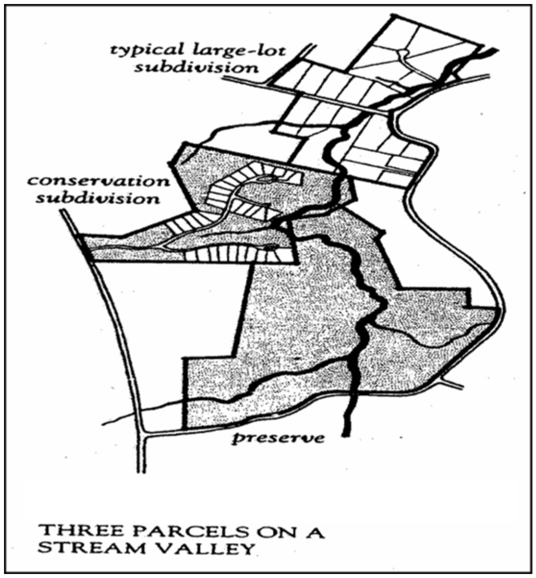
If the stormwater regulations for redevelopment districts are more stringent than those for greenfields, cities may find it difficult to attract developers. Rules for water protection and stormwater should be consistent watershed-wide.

During the site design process, pressures may develop to eliminate elements critical to a development district’s environmental performance. For example, a successful development district will shorten, combine, or eliminate auto trips. However, if pressure mounts to increase parking or decrease connections among uses, a city or county may be unable to reduce the amount of impervious surfaces, diminishing transportation and water benefits.

## Maintenance

Various design elements will direct a development district’s maintenance plan, although it is likely to include a combination of BMPs. Comprehensive redevelopment plans include common urban design elements like tree-lined streets, water features, and landscaping. Planners and stormwater professionals should look to these features to achieve urban design and water quality goals, and plan their maintenance procedures accordingly.

# Infrastructure Planning




## Practice Description

Infrastructure planning involves changes in the regional growth planning process to contain “sprawl” development. Sprawl development is the expansion of low-density development into previously undeveloped land. The American Farmland Trust has estimated that the United States is losing about 50 acres an hour to suburban and exurban development (Longman, 1998). This sprawl development requires local governments to extend public services to new residential communities whose tax payments often do not cover the cost of providing those services. For example, in Prince William County, Virginia, officials have estimated that the cost of providing services to new residential homes exceeds what is brought in from taxes and other fees by $1,600 per home (Shear and Casey, 1996).

Infrastructure planning concentrates public services such as water, sewer, roads, schools, and emergency services in the suburban fringe and directs new growth into previously developed areas, discouraging low-density development. Generally, this is done by drawing a boundary or envelope around a community, beyond which major public infrastructure investments are discouraged or not subsidized. Meanwhile, economic and other incentives are provided within the boundary to encourage growth in existing neighborhoods. By encouraging housing growth in areas that are already provided with public services, communities not only save infrastructure development costs, but reduce the impacts of sprawl development on urban streams and improve water quality within the watershed.

## Planning Considerations

Sprawl development occurs in all regions of the country and has recently become the subject of many new programs to counteract its impacts. These programs seldom focus on the water quality implications of sprawl growth, instead concentrating on economic and transportation issues. Even so, methods such as infrastructure planning can reduce the impact of new development. Promoting the infill and redevelopment of existing urban areas in combination with other better site design techniques will decrease impervious cover levels and lessen the amount of pollution discharged to urban streams.

Sprawl development negatively impacts water quality in several ways. One of the most significant impacts comes from the increase in impervious cover that is associated with “sprawl” growth. Rooftops, extension of road systems, and additional paved surfaces from driveways create an overall increase in imperviousness. This increase in the impervious cover level of an area directly influences local streams and water quality by increasing the volume of stormwater runoff. These elevated runoff levels impact urban streams in several ways, including enlarging stream channels, increasing sediment and pollutant loads, degrading stream habitat, and reducing aquatic diversity (Schueler, 1995). Sprawl has been reported to generate 43 percent more runoff that contains three times greater sediment loads than traditional development (South Carolina Coastal Conservation League, 1995).

## Design Criteria

Various techniques have been used to manage urban growth while conserving resources. Although none of these techniques specifically concentrates on infrastructure planning, each of the techniques recognizes that directing growth to areas that have been previously developed or promoting higher density development in areas where services exist prevents sprawl development and helps communities to mitigate the water quality impacts of economic growth. Two of these techniques are described below.

### Urban Growth Boundaries

This planning tool establishes a dividing line that defines where a growth limit is to occur and where agricultural or rural land is to be preserved. Often, an urban services area is included in this boundary that creates a zone where public services will not be extended.

### Infill/Community Redevelopment

This practice encourages new development in unused or underutilized land in existing urban areas. Communities may offer tax breaks or other economic incentives to developers to promote the redevelopment of properties that are vacant or damaged.

## Common Problems

Intense development of existing areas can create a new set of challenges for stormwater program managers. Stormwater management solutions can be more difficult and complex in ultra-urban areas than in suburban areas. The lack of space for structural stormwater controls and the high cost of available land where structural controls could be installed are just two problems that program managers will face in managing stormwater in intensely developed areas.

Infrastructure planning is often done on a regional scale and requires a cooperative effort among all the communities within a given region in order to be successful. Stormwater managers will need to develop lines of communication with other state and local agencies and community leaders to ensure that infrastructure plans direct growth to those areas that will have the least impacts on watersheds and water quality.

# Open Space Design


## Practice Description

Open space design is an alternative site planning technique that concentrates development to preserve open areas and green space. This is a rethinking of typical residential site development practices in that it gives extra consideration to preserving the natural integrity of the site. By keeping some areas in an undeveloped state, this design strategy can reduce negative impacts from stormwater such as increased runoff from impervious surfaces and pollutant inputs. Open space design has been shown to reduce construction costs while increasing property values because of the desirable open space amenity that is preserved. Other costs associated with additional stormwater management measures, clearing costs, and downstream flooding due to increased runoff volumes can also be reduced using open space design.

## Planning Considerations

The many misconceptions about open space design can be obstacles to its implementation. Some developers fear that designing to preserve open space will lead to longer plan reviews, higher costs, and lower market value. However, open space design can actually provide cost savings, as less area is cleared and fewer interventions are needed to manage stormwater. One open space development example (Liptan and Brown, 1996) demonstrated a cost savings of $800 per lot for site development. Other studies report cost savings for infrastructure ranging from 11 to 66%. Local ordinances may need to be revised to remove restrictions that stand in the way of implementing essential components of open space design.

According to the Center for Watershed Protection, open space designs have the following water quality advantages relative to a conventional development:

- Reduced impervious cover.
- Reduced pollutant loads to streams and other water resources.

- Reduced potential pressure to encroach on resource buffer areas.
- Reduced soil erosion potential by reducing the amount of clearing and grading on the site.
- Preservation of green space.
- Preservation of open space for recreation.
- Lower capital cost of development.
- Lower stormwater-management costs by concentration of runoff in one area and reducing runoff volumes.
- A wider range of feasible sites to locate stormwater BMPs.
- Lower costs of future public services needed by the development.
- Possible increase in property values.
- Creation of urban wildlife habitat "islands."
- Support for other community planning goals, such as pedestrian movement, neighborhood enhancement, farmland preservation, affordable housing, and architectural diversity (CWP, 1998).

The first step for many jurisdictions to encourage open space developments is to adopt a local ordinance that permits open space design in conventional residential zones, or to amend their current zoning ordinances to accomplish that goal. Essential elements of such an ordinance are described in the Design Criteria, Implementation, and Maintenance sections that follow. The Center for Watershed Protection has also developed an Open Space Model Ordinance to serve as a template for jurisdictions who wish to adopt such an ordinance (CWP, not dated). Whatever the method used to implement open space designs, it should include long-term provisions for the acceptable use and maintenance of the land that is preserved. With the proper regulations in place, the developer must create and follow a site plan for the project that meets the criteria below.

## Design Criteria

### Flexible Development Regulations

To implement open space design, the land use ordinance governing the area must allow for variations in site layout to help achieve a more compact development. Flexible and smaller lot sizes, varying setbacks, and frontage distances for the residential zone are some of the specific features that a developer working within an open space framework will need (USEPA, 2006b).

### Open Space and Natural Area Conservation Requirements

An open space design reduces the level of impervious cover as compared to a conventional development and preserves the maximum acreage for natural area conservation. To achieve stormwater benefits, the majority of the preserved open space must be contiguous. Some strategies to minimize the amount of paved area are unpaved walkways and the use of permeable paving materials. Open space can also be maximized by requiring narrower streets, smaller building setbacks, and shared driveways.

### Consolidation and Use of Open Space

The typical open space development creates 10-50% less impervious cover and reduces the need to clear and grade 35-60% of the site. The remaining open space can serve multiple functions. The site layout may preserve some areas to meet environmental requirements for stormwater management and conservation and others to provide future residents with attractive recreational amenities. Some of the high-priority uses for the preserved open space are

- Resource buffers,
- High-quality forest resources,
- Individual trees,
- Critical habitat areas,
- High-quality soil resources (CWP, not dated)

## Implementation

### Delineation of Boundaries

The boundaries of designated open space areas, recreation areas, stormwater management facilities, and green space shall be clearly delineated on plans, including record plats, and marked to distinguish these areas from private property. Development in designated open spaces in the future is prohibited.

### Density of Development

The total number of residential units allowable within an open space development shall not exceed the number of units that would otherwise be allowed in the existing zoning district using conventional development.

### Preservation of Open Space

The majority of the land preserved for open space should be contiguous to achieve the maximum environmental and recreational benefits. The model ordinance proposes that up to 50% of open space be preserved as green space. If open space design is used as a BMP for stormwater management, all Mississippi state design, construction, maintenance, and public safety requirements must be met.

## Common Problems

It is sometimes difficult to convince developers to adopt an open space design because of a concern that it will be both more expensive to develop and less marketable. The land use ordinances governing open space design must therefore foster development that meets market demands while protecting the environment. Decisions also need to be made about the locations where it is most beneficial to direct open space development. Finally, the issue of management is crucial to the long-term success of open space design. Long-term maintenance is primary among the concerns, but the developer must also delegate the necessary authority for managing issues such as liability and emergency vehicle access to a responsible entity in the public or private sector.

## Maintenance

Once established, common open space and natural conservation areas must be managed by a responsible party able to maintain the areas in a natural state in perpetuity. Typically, the open space is protected by one of these three strategies: a legally enforceable deed restriction, a conservation easement enforced by a local government or land trust, or maintenance agreements. In most communities, the authority for managing open space falls to a homeowner or community association or a land trust.

When managing open space as a natural area, annual maintenance costs are very low. The annual maintenance cost for managing an acre of natural area is less than $75 (CWP, 1998). It may be useful to develop a habitat plan for natural areas that may require periodic management actions.

# Protection of Natural Features

## Practice Description

Undeveloped sites often have natural features such as wetlands, riparian areas, floodplains, aquifer recharge areas, mature trees, woodlands, and other wildlife habitat, which provide environmental, aesthetic, and recreational benefits if preserved and protected from the impacts of construction and development. Restricted areas such as floodplains and steep slopes should also be protected from possible impacts from construction activities. Natural area protection is not limited to undeveloped land; properties that are being redeveloped might have attractive open space, well-drained soils, or riparian areas that should be identified and considered for preservation early in the planning process. The Better Site Design Handbook provides guidance on how a development can protect a site's natural features by reducing street lengths. It emphasizes the need for clearing and grading, applying open space design, promoting tree conservation, and taking advantage of conservation incentives (CWP, 1998).

Natural features and open space can be protected both during the development process and after a site is occupied through a combination of

(1) Site planning techniques,

(2) Construction site BMPs, and

(3) Measures employed after the site is in use.

## Planning Considerations

Natural area preservation has been achieved in numerous developments nationwide that have been both environmentally and economically successful. For example, the Chapel

Run residential development in Sussex County, Delaware, was initially proposed as a conventional residential development containing 142 half-acre lots. Site designers chose to preserve a wooded area with highly permeable soils as a means to control stormwater. To accommodate this open space, lot sizes were reduced from a half-acre to a quarter-acre and condensed into a cluster design, resulting in the preservation of approximately 68 percent of the site. Total capital costs for the clustered development were estimated to be $1,174,716, whereas a traditional design would have cost $2,460,200, yielding an estimated cost savings of $1,285,484 (Delaware DNREC, 1997). Many developments with open, shared areas have seen a greater increase in property value than those in comparable, traditional developments.

Additional examples of successful open space preservation, as reported by the National Association of Homebuilders, are summarized in the table below (NAHB, 2006).

| **Location** | **Description** | **Result** |
|---|---|---|
| Garnet Oaks, Bethel Township, PA | 80 homes on 58 acres | 51% of the land preserved as open space, including woodlands, tree specimens, and structures from the property's original estate<br>Housing price premiums are based in part on the lots' proximity to open space |
| Newpoint, Beaufort, SC | 124 single-family homes on 54 acres | Site layout preserved small wetlands and saved large existing trees, some in the greenway between street and sidewalk<br>The Riverside green and community dock provide neighborhood access |
| Prairie Crossing, Grayslake, IL | 337 single-family homes on 667 acres | 350 acres devoted to prairies, pastures, farms, fields, gardens, marshes, lakes<br>Community-supported organic garden<br>The community is the western anchor of the Liberty Prairie Reserve, a 2,500-acre preserve of forest, marshes, prairies, and farmland |
| The Fields of St. Croix, Lake Elmo, MN | 90 homes on 226 acres | 60 percent of the community's land preserved as permanent open space<br>Home sites are clustered near a wooded ridge overlooking the site's ponds and open space<br>Historic Civil War-era barn was preserved and used as a community center<br>Thirty acres of prairie restoration featuring native plants indigenous to the area<br>Existing wooded slopes, which are home to oak trees and provide excellent wildlife habitat, preserved<br>The open space is permanently guaranteed by a conservation easement granted to the Minnesota Land Trust |

Cost consideration comparisons for preserving natural areas and open space versus traditional development are difficult to determine because the quantity and type of natural features vary from site to site. In general, however, additional costs can be incurred when preserving natural areas because additional planning and inspections might be needed to meet local regulatory requirements using innovative site designs. Also, the need for smaller construction equipment could increase costs if equipment operators need to maneuver around trees and other protected features. These increased costs can be offset by decreased costs for clearing, grading, temporary erosion control, seeding, and landscaping because less area is disturbed. Savings can be substantial; the cost of clearing, grading, and installing stormwater control measures is estimated to be up to $5,000/acre, with annual maintenance costs adding an additional $800 to $1,500 (Schueler, 1997). Additionally, reduced infrastructure costs can be realized in developments that use clustering because of shorter road lengths, elimination of curbs and gutters, and the use of vegetated areas and swales instead of structural stormwater controls. Finally, long-term costs for landscape maintenance can be reduced because natural areas do not require the same level of maintenance as turf grass; eliminating the need to mow, fertilize, and perform other lawn maintenance activities can save a homeowner $1,000 to $1,500 annually (Delaware DNREC, 1997).

Developers can use conservation easements to maintain open space over the long term. This easement ensures that the land will not be developed and will remain protected.

## Design Criteria

Developments can be planned around significant environmental features, which can then be marketed as amenities. In *Conservation Design for Subdivisions* (1996), Randall Arendt describes a process to delineate a “development envelope” where buildings and infrastructure can be placed to avoid impacting natural features. The first step in this process is to assemble background information, which includes the following:

- Determine the local context: is the area agricultural, forested, etc.?
- Map significant features as candidate conservation areas, including floodplains, slopes, soils, wildlife habitats, woodlands, farmland, historical/cultural sites, views, aquifer recharge areas, and others.
- Rank conservation areas based on how special, unique, irreplaceable, environmentally valuable, historic, or scenic they are.
- Identify areas where buildings and infrastructure should be placed that would minimally impact conservation areas.
- Establish the layout of buildings and infrastructure, employing such techniques as clustering buildings and using smaller lots, shared driveways, and narrower streets (Arendt, 1996).

This process of site evaluation and design can allow significant features to be preserved while maintaining the desired overall site density (although density in localized parts of the development will be higher when open space is set aside). Some negative perceptions are associated with protecting natural features. Developers want to achieve a particular development density when building subdivisions or commercial sites. Also, for residential developments, lot size is an important factor in determining lot prices. Setting aside natural areas can take up space that would otherwise be used for yards, parking, transportation infrastructure, and other built features. Developers can accommodate overall site density using clustering techniques, smaller lots, and more efficient street layouts. To offset lost premiums from smaller individual lots, developers can market a lot's proximity to natural areas and attractive views as amenities.

## Implementation

When areas of the property with environmental significance have been identified for protection, extra care is needed during site preparation to protect these features. Developers should indicate a limit of disturbance and the location of protected areas in construction site stormwater pollution prevention plans (SWPPPs) and on site maps. Also, they should post signs with prohibitions and educate workers about the importance of and special considerations for the protected areas. Without training and explicit signage, areas slated for protection could be damaged by vehicle traffic, stored materials, and other construction-related activities. Construction operators should check areas regularly to identify problems and determine if additional controls such as more training, more explicit signage, and more obvious barriers are needed. Operators should also look for signs of unintended consequences of construction activities on the natural areas, such as changes in hydrology, flooding, or accidental spills, and take appropriate actions to mitigate the damage.

The following sections describe specific practices that developers and construction site operators can employ to protect each type of resource.

### Mature Trees or Woodlands

Surround the area to be protected with bright orange fencing placed at or beyond the tree's dripline. Prohibit clearing and grubbing, limit heavy equipment traffic, and prohibit material storage inside the barrier. Include signage that details specific prohibitions and educate employees. Visually monitor vegetation to ensure that it is not being damaged by construction activities (e.g., soil compaction from heavy equipment traffic might cause localized flooding in nearby natural areas).

### Steep Slopes

Steep slopes and related vegetation should be protected. Fence off these areas and assess whether additional erosion control is needed to prevent erosion. Check erosion controls on upslope areas that will be cleared and graded, and ensure that runoff from these areas is diverted away from or around the slope, using either a pipe slope drain or a diversion placed at the top of the slope. Post signs prohibiting heavy vehicle traffic and educate crews about the sensitivity of steep slopes to erosion.

### Well-Drained Soils and Aquifer Recharge Areas

Areas with well-drained soils and those that feed aquifers should be protected from compaction. Maintain vegetation if possible, or if the area is cleared, minimize heavy traffic by fencing the area and posting signs. Before planting permanent vegetation, aerate the soil to ensure that runoff infiltrates. These areas may be critical later to the success of post-construction BMPs by limiting the volume of runoff that needs to be treated.

### Wetlands and Riparian Areas

Establish a buffer around marshes, swamps, or other wetlands and along stream corridors in which no construction activity occurs. Avoid stream crossings wherever possible.

When absolutely necessary, set up perimeter sediment controls (e.g., silt fence) and visually monitor the protected areas, especially after each storm, to check for damage from flooding and for signs of impacts from the construction activity, including sedimentation, vegetation dieback, erosion, dumping, or fish kills. Set up stream crossings to minimize disturbance of streamside vegetation and in-stream habitat. Post signs and educate workers about the sensitive nature of the area and include prohibitions for storing or dumping materials.

### Wildlife Habitat

Contact a local wildlife authority if you find nests, dens, or other animal habitat on the property. These can be removed or relocated before construction begins.

The presence of threatened or endangered species or habitats critical to their survival on the site might require a consultation with the U.S. Fish and Wildlife Service or the National Marine Fisheries Service. You should ensure that you are in compliance with all regulations, including the Endangered Species Act.

### Floodplains

The placement of buildings in floodplains is typically restricted because of the risk of safety concerns and property damage, so these areas should remain outside the limit of disturbance. (Restrictions will vary from one municipality to the next, so check with local authorities about floodplain restrictions in your area.) Establish perimeter controls, including fencing, and post signage that prohibits dumping and material storage in these areas. Inspect protected areas on a regular basis to ensure that vegetation has not been disturbed and that no dumping has occurred.

## Common Problems

Concerns about cost and local ordinances are the most likely barrier to implementing a site plan that protects existing natural features. Education about the many cost savings associated with this strategy as well as techniques to achieve the desired number of units while protecting natural areas may be helpful to overcoming developers' reluctance. Local zoning codes should also be reviewed for provisions that restrict the use of clustering, reduced road widths, and other techniques for natural area preservation. Developers should work with local regulatory agencies to determine whether they can obtain waivers to protect natural features.

## Maintenance

Once a site is developed and occupied, natural areas become amenities for the site's occupants. These natural areas also become the responsibility of the owner or occupant. Developers should provide information about each natural area or protected feature, to describe the area's importance and outline the activities that should be prohibited to adequately protect the resource.

Developers should also provide guidance to occupants on how these areas should be maintained. For example, a preserved prairie or riparian stream buffer should not be mown or manicured like turf. Homeowners or maintenance crews would need to employ special procedures to preserve native species, such as using integrated pest management practices like hand-weeding and limiting chemical use. The same practices should be used in areas where traditional landscape maintenance activities could threaten water quality, such as in or adjacent to wetlands and riparian areas or where endangered species are present. Interpretive signage can be posted to educate occupants and visitors about the significance of the features and to describe prohibited activities such as mowing, dumping, and vehicle traffic. Barriers can be installed to protect the natural areas from damage without detracting from their aesthetics and function. These barriers can include strategic placement of low fences, walls, bollards, or large rocks that unobtrusively limit access to the areas.

# Redevelopment

Before

After


## Practice Description

Redevelopment occurs in areas that have previously been developed for another use. These sites are likely to be highly impervious and of limited value to the stormwater management system. The definitions of development and redevelopment vary in stormwater guidance documents and National Pollution D- E- S- stormwater permits. In some states and localities, development and redevelopment are subject to the same stormwater management requirements. Redevelopment of already impervious surfaces, however, can be a key strategy for reducing net increases in impervious surfaces and associated degradation to receiving waters. By recycling these sites and granting them new life, governments reap the broader benefits of development on an existing property by reusing impermeable surface and mitigating developmental impacts on a green field site. Because redevelopment will take advantage of existing roadways and building sites, it is likely to follow many of the Better Site Design principles associated with street width and length. Its primary advantage for stormwater management, however, is that it provides opportunities for conserving natural areas in the surrounding community that might otherwise be subject to greater development pressure (CWP, 1998).

## Planning Considerations

Redevelopment can be accomplished on a site-by-site basis, but it can also be part of a larger local or regional effort to spur investment and development activity. Many jurisdictions create redevelopment districts, such as business improvement districts, Main Street programs for older downtowns, brownfields programs, vacant property campaigns, and efforts to revive older, underperforming shopping malls. The transfer of development rights can help spur redevelopment by directing development demand to existing activity centers. In established development districts, infrastructure upgrades associated with redevelopment can be used for repairs such as replacing deteriorating pipes that are contributing to water quality impairments.

In districts with multiple redevelopment-ready properties, economic factors, such as location near amenities and proximity to transit, guide which properties are redeveloped first. Because these properties may or may not be the ones that will deliver the highest succession of stormwater benefits, it is helpful to prioritize areas that can provide the greatest opportunities for detention facilities or other desired BMPs.

Although redevelopment can just maintain the current level of stormwater runoff, by employing a strategic series of BMPs, this new development may actually lead to a net improvement in regional stormwater.

## Design Criteria

Design of redevelopment projects will vary considerably with land variations. Common land constraints include irregularly shaped properties, small lots, legacy contamination, and noncompliant building features/footprints. Water quality considerations can also influence the selection of structural BMPs used to manage the project's stormwater. In some cases, the main factor may be flow reduction, while in others cases the focus will be the filtration of nutrients or heavy metals.

### Stormwater Retrofit

In areas with degraded waterways, redevelopment activity can complement efforts to improve the quality and reduce the quantity of stormwater runoff. The BMPs chosen for redevelopment, however, need to consider the unique circumstances of the redevelopment project. Micro-detention, urban forestry techniques and structured soils are often recommended for urban areas. Green building techniques and green roofs may also be good choices. As noted above, cities and counties will want to coordinate infrastructure repair and upgrades with redevelopment efforts so that water and wastewater capacity are not barriers to redevelopment.

## Implementation

Redevelopment is highly useful in urban areas, especially where the area is fully built out. Some of the strategies for redevelopment are described below.

### Green Roofs

Green roofs help reduce the urban "heat island" effect as well as peak stormwater flows by absorbing stormwater on-site. The vegetated cover also helps protect and insulate the roof, extending its life and reducing heating and cooling costs. See more discussion on green roofs in the *Site Design* section of this chapter.

### Micro-Detention

Micro-detention techniques seek to absorb some or all stormwater runoff on the development site. Since the entire volume of stormwater generated on-site is rarely entirely infiltrated, micro-detention is typically only one of a series of BMPs. Common landscaping features, such as small garden areas, tree grates, perimeter hedges, and even rain gardens (also known as *Bioretention*) can enhance stormwater handling and micro-detention. In urban buildings with basements and underground garages, infiltration may occasionally not be an option. Pollutants that might be carried with infiltrating water should also be considered; hence, infiltrating techniques are not recommended for stormwater hotspots.

### Alternative Pavers and Porous Pavement

Alternative pavers, porous asphalt, and permeable concrete reduce stormwater flows by allowing water to infiltrate their porous surfaces and soak into the ground beneath. Pervious pavers can reduce runoff volumes at a considerably lower cost than traditional storm drain systems.

### Infrastructure Upgrades

Storm sewer overflows and leaking older pipes (referred to as inflow and outflow) can be significant environmental problems in urban areas. Redevelopment offers an opportunity, through enhanced tax revenues resulting from increased economic activity, to upgrade storm grates and pipes. However, capacity at wastewater treatment plants may be a barrier to redevelopment. In addition, the condition of receiving waters and total maximum daily limits can be hurdles to any development activity in an urban area.

### In-pipe and Small Structural Devices

A growing number of devices are coming on the market that provide a range of mitigation functions. These devices commonly work to separate large debris collected in runoff, intercept sediments, and improve water quality. They range in size, cost, and maintenance needs. They can be included in the suite of structural and nonstructural BMPs chosen for redevelopment projects and districts.

## Common Problems

As a stormwater strategy, redevelopment can require larger regional cooperation. To growing rural districts, a redevelopment strategy for established commercial centers might not be viewed as advantageous.

The BMPs required for redevelopment need to be compared to BMPs required for new development. Watersheds that choose redevelopment as a stormwater strategy should make sure the BMP cost and permit review requirements for redevelopment are comparable to those required for new development. Because redevelopment is often more complex than new development, design and building costs can be higher. Where infrastructure upgrades are needed, the costs can be considerable, particularly where treatment capacity or aging infrastructure is the limiting factor. However, in many cases, redevelopment projects can command a premium price, and some or all of the costs can be recovered.

# Street Design and Patterns

## Practice Description

The EPA, watershed researchers, and local governments have developed extensive guidance on the design of "green streets," which focuses on narrower widths, infiltration, and eliminating curbs and gutters. Streets designed to these specifications have substantial benefits for stormwater management. However, the underlying pattern of streets is just as influential, particularly as it relates to development patterns in a neighborhood and region.

Smart Growth street designs are based on a network of well-connected streets that support multiple transportation modes. Some Smart Growth approaches to street design include decreasing street widths, adjusting the vehicular level of service (LOS), creating LOS for other modes of transportation, and designing connected street networks to support multiple uses. The Better Site Design principles of the Center for Watershed Protection offer detailed guidance for how improvements to residential streets and parking lots can improve stormwater management in a community. Specific model development principles are offered with respect to street width and length, rights of way, driveways, cul-de-sacs, and alternative turnarounds (CWP, 1998).

## Planning Considerations

A variety of agencies control street and road designs at the regional level. State Departments of Transportation (DOT) typically control the design and operations of highways and larger arterial streets. When developing streets, state DOTs often refer to manuals such as the American Association of State and Highway Transportation Officials' (AASHTO) "Green Book," or manuals developed by the Institute for Transportation Engineers (ITE). Conventional street layouts today tend to follow a hierarchical system, with a multitude of smaller roads that serve residential areas feeding into larger roads and arterials. These arterials funnel traffic onto larger regional roads and highways. This system is often highlighted for its role in congestion, since the funneling of traffic creates congested chokepoints and severely limits alternative routes from place to place. This system also arose as part of a highly separated and dispersed land use system that is becoming less dominant in contemporary development.

As local governments and states demand connected, multi-modal street networks, AASHTO and ITE have recognized the need for alternative standards. In response, ITE has published “Traditional Neighborhood Development Street Design Guidelines” (1999) and “Neighborhood Street Design Guidelines” (2003). Public officials may also use the Better Site Design handbook (CWP, 1998) to conduct a review of their own codes and ordinances to determine if they allow for greener alternatives to the conventional street layout and network. The Model Development principles in that handbook are designed to facilitate changes to codes and ordinances where desired.

## Design Criteria

Smart Growth street designs can be divided into two categories: street design in new projects and modification of existing street patterns. The main benefit of Smart Growth street design rests on the ability to support a higher level of development intensity on a smaller footprint. This benefit manifests itself well at the regional and neighborhood levels. Alternative types of street designs can cut costs as well, reducing the need for paving materials for longer streets and more parking. For both redevelopment and new development projects, installing conventional sidewalks, curbs, and gutters is typically more expensive than the installation of the roadway itself.

### Street Design in New Projects

Smart Growth street designs incorporated into new projects are typically part of an overall site design that seeks to meet transportation, economic, and multi-modal objectives. On a local level, cities and counties such as Cary, North Carolina, and Portland, Oregon, have enacted “connected streets” policies so that new residential or mixed-use development projects have more than one link to neighboring retail, commercial, or transportation centers.

Standard road design practice has been to make decisions about stormwater BMPs after the roadway has already been designed. This not only limits options, but often focuses attention on end-of-pipe treatment BMPs rather than in-line measures or preventive measures, which are generally less expensive to build and maintain, and more effective at protecting water quality. For new development or redevelopment of any part of a transportation system, stormwater management features should be an integral part of the design, not “add-on” features. Though there is not one set standard, street designs should meet the following objectives:

- Support a mix of uses.
- Develop parking plans to optimize the number of spaces and layout for multi-modal connections.

- Incorporate features such as boulevard islands, rotary islands, parking lot islands, swales, and sidewalk tree and groundcover planters to capture, filter, and infiltrate runoff. These features may already be incorporated for aesthetics or traffic-calming purposes, and can be used to manage stormwater as well.

- Integrate sidewalks, crosswalks, and traffic-calming approaches to support bicycling, walking, and automobile traffic.

- Design for shorter block lengths.

- Engineer narrower street widths to facilitate pedestrian crossings and moderate automobile speed while meeting the needs of emergency responders.

- Provide access lanes, on-street parking and turning lanes to complement the land development design, sidewalks, and building setbacks.

Once the underlying layout has been established, transportation and stormwater engineers can look for additional strategies to further reduce stormwater volume and pollutants. Separate stormwater sewers typically discharge runoff with little or no treatment into receiving bodies. Thus, avoiding or minimizing the use of standard curb and gutter collection and conveyance systems should be a goal of any project.

Poorly draining soils do not have to preclude the use of these measures, as good designs and soil amendments can facilitate some level of infiltrative capacity almost anywhere. In areas with existing curb and gutter, and limited short-term options for major retrofits, the inlets and catch basins of storm sewers in a Smart Growth development or redevelopment project might require additional BMPs or design modifications.

### Modification of Existing Streets

Local governments can use several methods to incorporate Smart Growth features and stormwater benefits to existing streets. Some of these strategies will include

- Connecting disconnected streets, lanes, and cul-de-sacs,

- Where a new street is impossible, adding paths to link housing and other uses,

- Using unused streetscape to add public parking, increase the number of spaces, and introduce bike lanes.

These strategies are often used in connection with site design features like tree planters and vegetated bulb-outs that can be designed to handle and treat stormwater. Where possible, a street retrofit should take advantage of opportunities to improve the drainage system or add structural and non-structural BMPs to lessen the flow of stormwater volumes or filter pollutants. This will require a new approach to street repair and retrofits. Departments of Public Works and stormwater engineers will need to consult with land-use planners and site designers on reducing volume and treating stormwater before runoff enters the public conveyance system. In some areas, the stormwater inlets can be retrofitted with trash separation and filtration controls. A connected system need not be a formal grid of streets. Often the connections are determined not only by the street layout, but by linkages among activity centers like schools, neighborhoods, and jobs. Site planners might need to avoid introducing streets and hardscape in or around environmentally sensitive land or water resources.

## Effectiveness

The effectiveness of a Smart Growth street design can be at the street, neighborhood, and watershed levels. At the watershed level, the benefits of Smart Growth street designs for both redevelopment and new development emerge from absorbing development demand on a smaller footprint. During initial construction, less land disturbance results in less exposure and risk of sedimentation. Quantitatively, the best management practices will be preventative in nature since development takes place on a smaller area.

More transportation options mean that some car trips may be eliminated or shortened. The benefits of shrinking the footprint of parking and better managing existing street space are straightforward, but watersheds also benefit from reduced tailpipe-related deposits and from devoting what was single parking use to multi-use (shared parking and retail, for example). This efficiency also represents environmental benefits.

## Implementation

The objective of this BMP is to minimize impervious surface at the watershed level through a more thoughtful approach to roadway design, parking requirements, and connections between streets and modes of traffic. This may involve concentrating development in urbanized areas to preserve green space elsewhere in the watershed. Smart Growth street designs can involve more coverage per acre in a district, but far less on a sub-watershed scale.

For construction standards with respect to road widths and parking ratios, consult the BMPs given in this manual for:

- Green Parking (see *Site Design* section of this chapter),
- Narrower Residential Streets (see *Site Design* section of this chapter),
- Redevelopment (see *Planning* section of this chapter).

## Common Problems

As referenced, limitations to implementing innovative street designs might occur within the existing stormwater regulations. Blanket regulations that require land set-asides, mandatory infiltration, or swales can pose barriers to better site design. For example, mandated sizing requirements for swales might consume land needed for connections to a higher intensity transit district. While preserving these standards for certain parts of the watershed, incentives can be created for alternative street designs by modifying stormwater management requirements in targeted areas. In addition, there are reasonable, low-maintenance, stormwater-management measures that can be used (even in densely developed, highly impervious areas) that result in very low runoff.

Although most literature on stormwater management discourages “connected impervious surfaces,” local governments need to recognize that, as part of an overall Smart Growth design, “connected streets” confer stormwater benefits. The placement of intense and connected development is not appropriate in every part of a watershed. However, concentrating growth and development in certain parts of the watershed to protect more sensitive areas, such as headwaters, can be a viable strategy.

Developers who are accustomed to a conventional, separate pattern of development may sometimes resist new rules that require connecting internal streets to neighboring projects, adding sidewalks or introducing a mix of uses. Likewise, residents on unconnected streets may oppose efforts to improve connections within existing neighborhoods.

Finally, the street system alone will not bring about stormwater benefits. The relationship among the street layout, the development plan, and existing activity centers is crucial for obtaining stormwater benefits.

## Maintenance

Even in circumstances where the overall surface area of a Smart Growth street layout results in less impervious coverage, there are maintenance considerations. Separate stormwater sewers typically discharge runoff with little or no treatment into receiving bodies. Thus, typical maintenance considerations for curb and gutter designs include street sweeping, catch basin cleaning, clearing blocked sewer lines, repairing and replacing failed pipes, and other aspects of maintaining buried, hard infrastructure.

Maintenance of aboveground bioretention/infiltration features such as swales and infiltration trenches largely includes vegetation maintenance. Depending on locations and designs, removal of accumulated sediment and debris is also usually necessary. Porous or pervious surface materials generally do not have additional maintenance requirements. In-line and end-of-pipe commercial swirl or filter devices require regular clean-out. All types of systems should have regular inspections to ensure they are functioning properly.

# Urban Forestry

## Practice Description

Urban forestry is the study of trees and forests located in and around towns and cities. Since trees absorb water, patches of forest and the trees that line streets can help provide some of the stormwater management required in an urban setting. Urban forests help break up a landscape of impervious cover, provide small but essential green spaces, and link walkways and trails.

Successful urban forestry requires a conservation plan for individual trees as well as forest areas larger than 10,000 sq ft. A local forest or tree ordinance is one technique for achieving conservation and, when specific measures to protect and manage these areas are included, urban forests and trees can help reduce stormwater management needs in urban areas. Guidance on conservation of natural areas in the Better Site Design handbook is useful for jurisdictions that wish to incorporate urban forestry in their stormwater management plan. Model development principles that apply to urban forestry include clearing and grading, tree conservation, riparian buffers, and stormwater outfalls (CWP, 1998).

## Planning Considerations

From a stream preservation perspective, it is ideal to preserve as much contiguous forest as possible. However, this may not be an option in many urban areas. If forested areas are fragmented, it is ideal to retain the closest fragments together. In rapidly urbanizing areas, where clearing and grading are ongoing, tree preservation areas should be clearly marked.

Delineating lines along a critical root zone (CRZ) rather than a straight line is essential to preserving trees. It can also help reduce homeowner complaints about tree root interference into sewer or septic lines.

Numerous environmental and stormwater benefits result from urban forestry. Urban forests can act as natural stormwater management areas by filtering particulate matter (including pollutants, some nutrients, sediments, and pesticides) and by absorbing water. A study done by the U.S. Department of Agriculture's Center for Urban Forest Research found that a medium-sized tree can intercept 2,380 gallons of rain per year (CUFR, not dated).

Trees also absorb carbon dioxide, decrease temperatures, and provide habitat for urban wildlife. Urban forestry reduces noise levels and provides recreational benefits. There are numerous economic benefits to urban forests, including proven increases in property values. In addition, by preserving trees and forests, the costs of clearing and grading as well as erosion and sediment control can be reduced during construction. Maintenance costs are also minimized by keeping areas as natural as possible.

**Annual maintenance costs of different types of green spaces** (CWP, 1998)

| Land Use | Approximate Annual Maintenance Costs |
|---|---|
| Natural Open Space<br>*Only minimum maintenance, trash/debris cleanup* | $75/acre/year[1] |
| Lawns<br>*Regular mowing* | $270 to $240/acre/year[2] |
| Passive Recreation | $200/acre/year[1] |

[1] "Economic Impacts of Protecting Rivers, Trails and Greenway Corridors," 4th ed. 1995. Rivers, Trails and Conservation Assistance Program, National Park Service, Western Office, San Francisco, CA.
[2] "The Economic Benefits of Wildlife Habitat Enhancement on Corporate Lands." 1992. Wildlife Habitat Enhancement Council, Silver Springs, MD.

## Design Criteria

An urban forestry plan should include measures to establish, conserve, or reestablish preservation areas. The basic building block of the plan is the critical root zone, or the area around a tree required for its survival. The CRZ is determined by tree size, species, and soil conditions. For isolated specimen trees, the CRZ can be estimated as 1/2 feet of radial distance for every inch of tree diameter. In larger areas of trees, the CRZ of forests can be estimated at 1 foot of radial distance for every inch of tree diameter, or a minimum of 8 feet.

### Forest Preservation Ordinance

A forest preservation ordinance is one way to set design standards outlining how a forest should be preserved and managed. The ordinance should outline some basic management techniques and contain some of the following typical elements of a forest conservation plan:

- A map and a narrative description of the forest and surrounding area that includes topography, soils, streams, current forested and unforested areas, tree lines, critical habitats, and 100-year floodplain.
- An assessment that establishes preservation and reforestation areas.
- A forest conservation map that outlines forest retention areas, reforestation, protective devices, limits of disturbance, and stockpile areas.
- A schedule of any additional construction in and around the forest area.
- A specific management plan, including tree and forest protection measures.
- A reforestation and a forestation plan.

### Site-Level Tree Preservation

An ordinance can also be developed that addresses tree preservation at the site level, both during construction and post-construction. This type of ordinance can be implemented on a smaller scale and integrated with a proposed development's erosion and sediment control and stormwater pollution prevention plans, which many communities require of new developments.

American Forests, a non-profit organization dedicated to preserving and restoring forests, adopted an ecosystem restoration and maintenance agenda in 1999. Their goal is to assist communities in planning and implementing tree and forest actions to restore and maintain healthy ecosystems and communities (American Forests, 2000). The agenda presents the organization's core values and policy goals as the basis for policy statements. It also provides information to help community-based partners prepare their own policy statements. Key policy goals include

- Increasing public and private sector investment in ecosystem restoration and maintenance activities;
- Promoting an ecosystem workforce through training, apprenticeship programs, and new job opportunities;
- Building support for innovative monitoring systems to ensure collaborative learning and adaptive management; and
- Encouraging a "civic science" approach to ecosystem research that respects local knowledge, seeks community participation, and provides accessible information for communities.

## Common Problems

One of the biggest limitations to urban forestry is development pressure. Ordinances, conservation easements, and other techniques designed into management programs can help alleviate future development pressures. The size of the land may also limit the ability to protect individual trees. In such areas, a tree ordinance may be a more practical approach.

Forests may also harbor undesirable wildlife elements such as insects and other pests. If forests border houses, this may be a concern for residents.

## Maintenance

Maintenance considerations for urban forests may require fringe landscaping and trash pickup. By using native vegetation and keeping the area as natural as possible, maintenance efforts can be minimized.

# Alternative Turnarounds

## Practice Description

Alternative turnarounds are designs for end-of-street vehicle turnaround that replace cul-de-sacs and reduce the amount of impervious cover created in residential neighborhoods. Cul-de-sacs are local access streets with a closed circular end that allows for vehicle turnarounds. Many of these cul-de-sacs can have a radius of more than 40 feet. From a stormwater perspective, this creates a huge bulb of impervious cover, increasing the amount of stormwater runoff. For this reason, reducing the size of cul-de-sacs through the use of alternative turnarounds or eliminating them altogether can reduce the amount of impervious cover created at a site.

There are numerous alternatives to the traditional 40-foot cul-de-sac that create less impervious cover. These include reducing cul-de-sacs to 30-foot radius, hammerheads, loop roads, and creating pervious islands in the center.

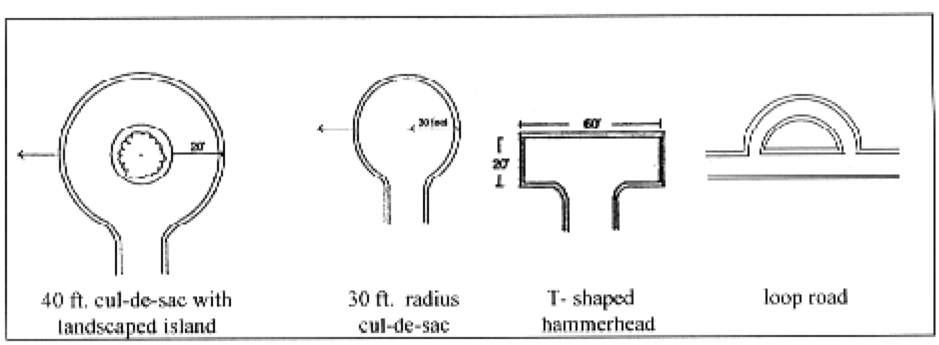



**Figure 1: Four turnaround options for residential streets**

Figure 1: Alternative turnaround options (CWP, 1998)

## Planning Considerations

Alternative turnarounds can be applied in the design of residential, commercial, and mixed use developments. Combined with alternative pavers, green parking, curb elimination and other techniques, the total reduction to site impervious cover can be dramatic, reducing the amount of stormwater runoff from the site. With proper designs, much of the remaining stormwater can be treated on-site.

Sufficient turn-around area is a significant factor to consider in the design of cul-de-sacs. In particular, the types of vehicles entering into the cul-de-sac should be considered. Fire trucks, service vehicles, and school buses are often cited as examples for increased turning radii. However, research shows that some fire trucks are designed for smaller turning radii. In addition, many new larger service vehicles are designed using a tri-axle, and schools buses usually do not enter individual cul-de-sacs.

Implementation of alternative turnarounds will also have to address local regulations and marketing issues. Communities may have specific design criteria for cul-de-sacs and other alternative turnarounds. Also, cul-de-sacs are often featured as highly marketable and, while alternative turnarounds can still capture the end of the street appeal, actual research on market preference is not widely known. Local regulations often dictate requirements for turnaround radii, and some of the alternatives may not be allowed by local codes. In addition, marketing perceptions may also dictate designs, particularly in residential areas. While changing local codes is no small effort, by initiating a local site planning roundtable, communities can change some of these regulations through a cluster ordinance or through a collective effort to review local codes to promote better site design.

Since alternative turnarounds reduce the amount of impervious cover created, construction savings can be an incentive (asphalt costs \$0.50–\$1.00 per square foot in materials alone). Bioretention is estimated at \$6.40 per cubic foot and, while it costs more than providing a naturally vegetated area, it can help reduce overall stormwater costs.

## Design Criteria

The primary goals of the alternative turnaround BMP is to reduce impervious surface. This can be achieved through reducing the size of cul-de-sacs or eliminating cul-de-sacs from roadway design. The designs in Figure 1 above show four options for achieving this goal, which range from placing a planter in the center of a traditional cul-de-sac to creating a small loop in the road to route traffic effectively while using less pavement.

## Maintenance

If islands are constructed as part of a turnaround, these areas will need to be maintained. Kept as a natural area, the costs could be minimal. Bioretention areas will also require maintenance. The other options create less asphalt to repave, and maintenance will remain the same and cost less ("Alternative Turnarounds," USEPA 2006).

# Eliminating Curbs and Gutters


## Practice Description

This practice promotes grass swales as an alternative to curbs and gutters along residential streets. Curbs and gutters are designed to quickly convey runoff from the street to the storm drain and, ultimately, to a local receiving water. Consequently, they provide little or no removal of stormwater pollutants. Indeed, curbs often act as traps where deposited pollutants remain until the next storm washes them away. Many communities require curbs and gutters as standard elements of road sections. In fact, many communities discourage the use of grass swales. Revisions to current local road and drainage regulations are needed to promote greater use of grass swales along residential streets.

## Planning Considerations

The use of engineered swales in place of curbs and gutters should be encouraged in low- and medium-density residential zones where soils, slope, and housing density permit. However, eliminating curbs and gutters is generally not feasible for streets with high traffic volume or extensive on-street parking demand (i.e., commercial and industrial roads). Nor is it a viable option in arid and semi-arid climates where grass cannot grow without irrigation.

Removal of curbs and gutters decreases the peak flow discharge to receiving waters. Furthermore, under the proper design conditions, grass swales can be effective in removing pollutants from urban stormwater (Schueler, 1996).

Engineered swales are a much less expensive option for stormwater conveyance than the curb and gutter systems they replace. Curbs and gutters and the associated underground storm sewers have been documented to cost as much as $36 per linear foot, which is roughly twice the cost of a grass swale (Schueler, 1995). Consequently, when curbs and gutters are eliminated, the cost savings can be considerable.

## Design Criteria

A series of site factors must be evaluated to determine whether a grass swale is a viable replacement for curbs and gutters at a particular site.

### Contributing drainage area

Most individual swales cannot accept runoff from more than 5 acres of contributing drainage area. Typically, they serve 1-2 acres each.

### Soils

The effectiveness of swales is greatest when the underlying soils are permeable (hydrologic soil groups A and B). The swale may need more engineering if soils are less permeable.

### Slope

Swales generally require a minimum slope of 1 % and a maximum slope of 5 %.

### Water Table

For most designs, swales should be avoided if the seasonally high water table is within 2 feet of the proposed bottom of the swale.

### Development Density

The use of swales is often difficult when development density becomes more intense than four dwelling units per acre, simply because the number of driveway culverts increases to the point where the swale essentially becomes a broken-pipe system. Typically, grass swales are designed with a capacity to handle the peak flow rate from a 10-year storm, and fall below erosive velocities for a 2-year storm.

## Construction and Installation

Although there are different design variations of the grassed swale, some design considerations are common to all. An overriding similarity is the cross-sectional geometry. Swales often have a trapezoidal or parabolic cross section with relatively flat side slopes (flatter than 3:1 horizontal: vertical), though rectangular and triangular channels can also be used. Designing the channel with flat side slopes increases the wetted perimeter. The wetted perimeter is the length along the edge of the swale cross section where runoff flowing through the swale contacts the vegetated sides and bottom. Increasing the wetted perimeter slows runoff velocities and provides more contact with vegetation to encourage sorption, filtering, and infiltration. Another advantage to flat side slopes is that runoff entering the grassed swale from the side receives some pretreatment along the side slope.

Another similarity among designs is the type of pretreatment needed. In all design options, a small forebay should be used at the front of the swale to trap incoming sediments. A pea gravel diaphragm, a small trench filled with river-run gravel, should be constructed along the length of the swale and used as pretreatment for runoff entering the sides of the swale. Other features designed to enhance the performance of grassed swales are a flat longitudinal slope (generally between 1 percent and 2 percent) and a dense vegetative cover in the channel. The flat slope helps to reduce the flow velocity within the channel. The dense vegetation also helps reduce velocities, protects the channel from erosion, and acts as a filter to treat stormwater runoff. During construction, it is important to stabilize the channel while the vegetation is becoming established, either with a temporary grass cover or with natural or synthetic erosion control products. In addition to treating runoff for water quality, grassed swales must convey runoff from larger storms safely. Typical designs allow the runoff from the 2-year storm (i.e., the storm that occurs, on average, once every two years) to flow through the swale without causing erosion. Swales should also have the capacity to pass larger storms such as a 10-year storm safely.

The following discussion identifies design and construction practices for three variations of open-channel practices: the grassed channel, the dry swale, and wet swale. For a detailed discussion of *Grass Swales*, see *Volume 1 – Chapter 4*.

### Grassed Channels

Of the three grassed swale designs, grassed channels are the most similar to a conventional drainage ditch, with the major differences being flatter side slopes and longitudinal slopes, and a slower design velocity for water quality treatment of small storm events. Of all of the options, grassed channels are the least expensive but also provide the least reliable pollutant removal. An excellent application of a grassed channel is as pretreatment to other structural stormwater practices. A major difference between the grassed channel and many other structural practices is the method used to size the practice. Most stormwater-management water quality practices are sized by volume. This method sets the volume available in the practice equal to the water quality volume, or the volume of water to be treated in the practice. The grassed channel is a flow rate-based design. Based on the peak flow from the water quality storm (this varies regionally, but a typical value is the 1 inch/24-hr storm), the channel should be designed so that runoff takes, on average, 10 minutes to flow from the top to the bottom of the channel. A procedure for this design can be found in Design of Stormwater Filtering Systems (CWP, 1996).

### Dry Swales

Dry swales are similar in design to bioretention areas. These designs incorporate a fabricated soil bed into their design. The native soil is replaced with a sand/soil mix that meets minimum permeability requirements. An underdrain system is installed at the bottom of the soil bed. This underdrain is a gravel layer that encases a perforated pipe. Stormwater treated in the soil bed flows into the underdrain, which routes this treated stormwater to the storm drain system or receiving waters. Dry swales are a relatively new design, but studies of swales with a native soil similar to the man-made soil bed of dry swales suggest high pollutant removal.

### Wet Swales

Wet swales intersect the groundwater and behave similarly to a linear wetland cell (see *Constructed Stormwater Wetland Practice*). This design variation incorporates a shallow permanent pool and wetland vegetation to provide stormwater treatment. This design also has potentially high pollutant removal. Wet swales are not commonly used in residential or commercial settings because the shallow standing water may be a potential mosquito-breeding area ("Grassed Swales," USEPA 2006).

## Common Problems

A number of real and perceived limitations hinder the use of grass swales as an alternative to curb and gutters:

*The pavement edge along the swale can experience more cracking and structural failure, increasing maintenance costs.* The potential for pavement failure at the road/grass interface can be alleviated by "hardening" the interface with grass pavers or geo-synthetics placed beneath the grass. Other options include placing a low-rising concrete strip along the pavement edge.

*The shoulder and open channel will require more maintenance.* In reality, maintenance requirements for grass channels are generally comparable to those of curb and gutter systems. The major requirements involve turf mowing, debris removal, and periodic inspections.

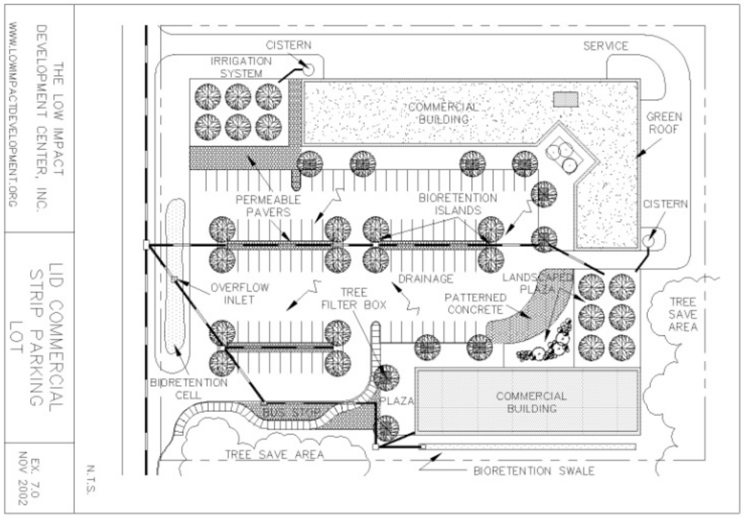
*Some grass swales can have standing water, which make them difficult to mow, and can cause nuisance problems such as odors, discoloration, and mosquitoes.* In reality, grass channels are not designed to retain water for any appreciable period of time.

Other concerns involve fears about utility installation and worries that the grass edge along the pavement will be torn up by traffic and parking. While utilities will need to be installed below the paved road surface instead of in the right-of-way, most other concerns can frequently be alleviated through the careful design and integration of the open channels along the residential street.

## Maintenance

The major maintenance requirement for grass swales is mowing during the growing season, a task usually performed by homeowners. In addition, sediment deposits may need to be removed from the bottom of the swale every ten years or so, and the swale may need to be tilled and re-seeded periodically. Occasionally, erosion of swale side slopes may need to be stabilized. The overall maintenance burden of grass swales is low in relation to other stormwater practices, and it is usually within the competence of the individual homeowner. The only major maintenance problem that might arise pertains to "problem" swales that have standing water and are too wet to mow. This particular problem is often alleviated by amending the soil with rocks and well-drained soils to promote drainage.

# Green Parking




## Practice Description

Green parking uses a combination of techniques to decrease the parking lot's impact on surrounding drainage patterns. Applied correctly, this can dramatically reduce impervious cover and, consequently, the amount of stormwater runoff. Some techniques include setting maximums for the number of parking spaces created, minimizing the dimensions of parking lot spaces, using permeable pavers in overflow parking areas, using bioretention areas to treat stormwater, encouraging shared parking, and providing economic incentives for structured parking. Green parking strategies can be used in both new developments and redevelopment ("Green Parking," USEPA 2006).

## Planning Considerations

Applied together, green parking techniques can effectively reduce the amount of impervious cover, protect local streams, save expenses on stormwater management, and visually enhance a site. Proper bioretention area design can help meet stormwater management and landscaping requirements while keeping maintenance costs at a minimum. Some limitations to applying green parking techniques include applicability, cost, and maintenance. For example, shared parking is practical only in mixed-use areas, and structured parking may be limited by the cost of land versus construction.

The pressure to provide parking spaces can come from fear of complaints as well as bank loan requirements. This may pressure developers to construct more parking than necessary and to be a barrier to providing the greenest parking lot possible. Green parking lots, however, can dramatically reduce the amount of impervious cover created. The level of effectiveness depends on how much impervious cover is reduced as well as the combination of techniques used to provide the greenest parking lot. While the pollutant removal rates of bioretention areas have not been directly measured, their capability is considered comparable to a dry swale, which removes 91% of total suspended solids, 67% of total phosphorous, 92% of total nitrogen, and 80-90% of metals (Schueler, 1996).

# Implementation

## Minimize Dimensions of Parking Spaces

Minimizing the dimensions of parking spaces is another green parking lot technique. Besides reducing the length and width of all spaces, parking stall dimensions can be reduced by providing compact vehicle spaces. While large sport utility vehicles (SUVs) are often cited as barriers to stall minimization techniques, most local parking codes require stall widths wider than the widest SUVs ("Green Parking," USEPA 2006).

## Amend Parking Ratios

Many commercial areas require excessively high parking ratios based upon the highest hourly parking demand during peak seasons. Changing the calculation method to account for actual average parking demand instead can help jurisdictions set a maximum number of parking spaces. The table below provides examples of conventional parking requirements and compares them to average parking demand.

| Conventional Minimum Parking Ratios (Source: ITE, 1987; Smith, 1984; and Wells, 1994) | | | |
|---|---|---|---|
| Land Use | Parking Requirement | | Actual Average Parking Demand |
| | Parking Ratio | Typical Range | |
| Single family homes | 2 spaces per dwelling unit | 1.5 - 2.5 | 1.11 spaces per dwelling unit |
| Shopping center | 5 spaces per 1000 $ft^2$ GFA | 4.0 - 6.5 | 3.97 per 1000 $ft^2$ GFA |
| Convenience store | 3.3 spaces per 1000 $ft^2$ GFA | 2.0 - 10.0 | -- |
| Industrial | 1 space per 1000 $ft^2$ GFA | 0.5 - 2.0 | 1.48 per 1000 $ft^2$ GFA |
| Medical/ dental office | 5.7 spaces per 1000 $ft^2$ GFA | 4.5 - 10.0 | 4.11 per 1000 $ft^2$ GFA |
| GFA = Gross floor area of a building without storage or utility spaces. | | | |

## Alternative Pavers

Utilizing alternative pavers is also an effective green parking technique. These can replace conventional asphalt or concrete in both new developments and redevelopment projects. Alternative pavers can range from medium to relatively high effectiveness in meeting stormwater quality goals.

The different types of alternative pavers include gravel, cobbles, wood mulch, brick, grass pavers, turf blocks, natural stone, pervious concrete, and porous asphalt.

### Bioretention Areas

Bioretention areas can effectively treat stormwater in a parking lot. Stormwater is directed into a shallow, landscaped area and temporarily detained. The runoff then filters down through the bed of the storage area and is infiltrated into the subsurface or collected into an underdrain pipe for discharge into a stream or another stormwater facility. Bioretention areas can be attractively integrated into landscaped areas and can be maintained by commercial landscaping firms. For detailed design specifications of bioretention areas, refer to the *Bioretention (Rain Gardens) Practice*.

### Shared & Structured Parking

Shared parking in mixed-use areas and structured parking are also green parking techniques that can further reduce the conversion of land to impervious cover. A shared parking arrangement could include usage of the same parking lot by an office space that experiences peak parking demand during the weekday with a church that experiences parking demands during the weekends and evenings. Costs may dictate the usage of structure parking, but building upwards or downwards can help minimize surface parking.

## Common Problems

As referenced above, cost and maintenance are the major limitations on green parking techniques. Alternative pavers are currently recommended only for overflow parking because of the considerable cost of maintenance, and bioretention areas can be costly to construct. Strategies like setting maximums for parking spaces, minimizing stall dimensions, and encouraging shared parking can result in considerable construction cost savings, however, and all of the green parking techniques can also reduce stormwater management costs.

### Alternate Pavers

Alternative pavers require proper installation and more maintenance than conventional asphalt or concrete. Accessibility, climate, soil type, traffic volume, and long-term performance should be considered along with costs and stormwater quality controls when choosing paving materials. Use of alternative pavers in cold climates will require special consideration since snow shovels are not practical for many of these surfaces. Sand is particularly troublesome if used with paving blocks since the sand that ends up in between the blocks cannot effectively wash away or be removed. In addition, salt used to de-ice can infiltrate directly into the soil and cause potential groundwater pollution.

Soil types will affect the infiltration rates and should also be considered when using alternative pavers. Clayey soils (D soils) will limit the infiltration on a site. If groundwater pollution is a concern, use of alternative pavers with porous soils should be carefully considered.

## Maintenance

### Alternate Pavers

The durability and maintenance cost of alternative pavers also limits use to low traffic-volume areas. For the reasons cited above, alternative pavers for parking are recommended for light-use residential areas that do not require accessibility and for parking overflow areas. At the same time, alternative pavers can abate stormwater management costs. Used in combination with other better site design techniques, the cumulative effect on stormwater can be dramatic.

## Bioretention

Bioretention requires regular landscaping maintenance, including measures to ensure that the area is functioning properly. In many cases, bioretention areas require intense maintenance initially, but less is needed over time. Many tasks can be completed by a landscaping contractor, who may already be hired at the site. Landscaping maintenance requirements can be less resource intensive than traditional landscaping practices such as elevated landscaped islands in parking areas.

**Typical Maintenance Activities for Bioretention Areas** ("Green Parking," USEPA 2006)

| **Activity** | **Schedule** |
|---|---|
| Remulch void areas<br>Treat diseased trees and shrubs<br>Mow turf areas | As needed |
| Water plants daily for 2 weeks | At project completion |
| Inspect soil and repair eroded areas<br>Remove litter and debris | Monthly |
| Remove and replace dead and diseased vegetation | Twice per year |
| Add mulch<br>Replace tree stakes and wires | Once per year |

# Green Roofs

## Practice Description

There are two primary strategies for constructing green roofs (vegetated roof covers and roof gardens): to detain rainfall and to promote evapotranspiration of runoff. Some innovative projects even capture larger quantities of water for management with strategies such as roof ponding areas and cisterns. The vegetated roof blankets the roof area with a layer of living vegetation. These are particularly effective when applied to extensive roofs, such as those commonly used on commercial, multifamily, and institutional buildings. However, they can be applied to virtually any building, including single-family residences. Vegetated roof covers are an effective means of retarding runoff from roof surfaces. Initially during a rainfall event, nearly all precipitation striking the foliage is intercepted. As rain continues, water percolates into and begins to saturate the growth media and root zone of the cover. Significant quantities of water do not begin to drain from the roof until the field capacity of the medium is filled. For small rainfall events, little runoff occurs and most of the precipitation eventually returns to the atmosphere.

Roof gardens (which are also called "intensive green roofs") are landscaped environments that may include planters and potted shrubs and trees. Roof gardens can be custom-made naturalized areas, designed for outdoor recreation, and perched above congested city streets. Because of the special requirements for access, structural support, and drainage, roof gardens are found most frequently in new construction. The services of a professional engineer are required to evaluate the structural and drainage constraints associated with roof garden design. For larger storms, both types of green roofs can delay and slow the peak runoff significantly.

## Planning Considerations

Green roofs are useful for a wide range of construction types. They provide very effective stormwater management for small- to mid-size events. By employing a green roof, developers can often conserve space on-site that would otherwise be required for detention or retention facilities. Experts believe this strategy may even extend the life expectancies of roofs, primarily by shielding from ultraviolet light (UV and temperature extremes. It reduces heat island effects caused by impervious surfaces, and can even bring down heating and cooling costs in the building. It adds aesthetic value to residential and commercial property; provides attractive textures and colors; and creates habitat for birds and insects. There are some disadvantages to this BMP, however. It often requires additional structural strengthening to hold the weight of the structure. Although roof gardens require only normal garden maintenance, the location may make it more difficult to inspect and correct problems. The vegetated roof cover style of green roof cannot be walked on, although a roof garden can handle foot traffic. Buildings that employ rooftop detention strategies may experience leaks. These are also among the most expensive practices per square foot of treated area.

## Design Criteria

When preparing a design for a green roof, whether it is a vegetated roof or a roof garden, there are several requirements that must be met. The project must begin with a vegetation plan prepared by a horticulturalist versed in green roofs. The design and implementation will also require the participation of a structural engineer to verify that the roof structure and structure strength are adequate to accommodate these BMPs. The design must include access to the roof for regular inspection and maintenance. If roof slopes are greater than 20 degrees, support systems must be installed to avoid slippage of the growing medium and plants. Specific design criteria for these two primary types of green roofs are detailed below.

### Vegetated Roof Covers

Because of recent advances in synthetic drainage materials, vegetated roof covers are now feasible on most conventional flat and gently sloping roofs. A lightweight, efficient drainage layer is placed between the growth medium and the impermeable membrane protecting the roof surface. This layer rapidly conveys water off the roof surface and prevents it from ponding. Vegetated roof covers also serve to protect roof materials and prolong their life, primarily by shielding from UV and temperature extremes. European data show that green roofs can double the life span of a roof.

Although vegetative roof covers are most effective during the growing season, they are also beneficial during the winter months if the vegetative matter from the dead or dormant plants is left in place and intact.

The emphasis of the design should be to promote rapid roof drainage and minimize the weight of the system. It is advisable to obtain the services of specialized installers because of the many factors that may influence the design.

### Waterproof Roof Liner

In some instances, the impermeable lining can be the watertight tar surface, which is conventional in flat-roof construction. However, where added protection is desired, a layer of plastic or a rubber membrane can be installed immediately beneath the drainage net or sheet drain.

### Drainage Net or Sheet Drain

The drainage net or sheet drain is a continuous layer that underlies the entire cover system. A variety of lightweight, high-performance, drainage products function well in this environment. The product selected should be capable of conveying the discharge associated with the design storm without ponding water on top of the roof cover. The drainage layer must have a good hydraulic connection to the roof gutters, drains, and downspouts. To prevent the growth medium from clogging the drainage layer and to prevent roots from penetrating the roof surface, a geotextile should be installed immediately over the drainage net or sheet drain. Some products have the geotextile bonded to the upper surface of the drainage material. A root retardant (such as copper sulfate) is typically included in this geotextile.

### Lightweight Growth Medium

The depth of the growth medium should be as small as the cover vegetation will allow, which is typically 3 to 6 inches. Low-density substrate materials with good water-retention capacity (e.g., mixtures containing expanded slate, expanded shale, expanded clay, and terra cotta) should be specified. Media appropriate for this application will retain 40 to 60 percent water by weight and have bulk dry densities between 35 and 50 lb/ft$^3$. The makeup of the media will vary depending on the types of plants used, but an example media makeup would be 55% expanded slate, 30% root zone sand, and 15% compost. Care should be taken when specifying compost because it will break down over time, and the depth of the media will therefore decrease.  A photograph of expanded slate is provided as Figure 1. Earth and topsoil are too heavy for most applications, as well as being too wet for succulent and other recommended vegetation, and too dry for grasses.

Figure 1
Expanded Slate

### Vegetation

A limited number of plants can thrive in the roof environment where periodic rainfall alternates with periods that are hot and dry. Effective plant species must tolerate mildly acidic conditions and poor soil; prefer very well-drained conditions and full sun; tolerate dry soil; and be vigorous colonizers. It should also be noted that conditions can be much wetter for longer periods near a gutter or drain and drier near the peaks. Succulents have shown to be very successful in vegetative roof covers, and are preferred to grasses. Both annual and perennial plants can be used. Vegetative roof covers may need provisions for occasional watering (e.g., conventional lawn sprinklers) during extended dry periods. A vegetation plan prepared by a horticulturalist versed in green roof vegetation is required.

### Hydraulics

Vegetative roof covers influence runoff in two ways: intercepting rainfall during the early part of a storm, and limiting the release rate. Hydrologic properties are specific to the growth medium. If information is not provided by the supplier, prospective media should be laboratory-tested to establish:

- Porosity
- Moisture content at field capacity
- Moisture content at the wilting point
- Saturated hydraulic conductivity

Rainfall retention properties are related to field capacity and wilting point. Appropriate media for this application should be capable of retaining water at the rate of 40 percent by weight, or greater. The medium must be uniformly screened and blended to achieve its rainfall retention potential. During the early phases of a storm, the media and root systems of the cover intercept and retain most of the rainfall, up to the retention capacity. For instance, a 3-inch cover with 40 percent retention potential effectively controls the first 1.2 inch of rainfall. Although some water percolates through the cover during this period, this quantity is generally negligible compared with the direct runoff rate without the cover in place. Capture rates are dependent on rainfall intensity, antecedent rainfall, time of year, evapotranspiration, and roof pitch. Green roofs on pitches steeper than 1:12 do not function as well as for water quality and quantity control. Vegetated roof covers should be kept on slopes of 8 percent or less, if they are being used to mitigate water quality or quantity.

Once the field capacity of the cover is attained, water drains freely through the medium at a rate that is approximately equal to the saturated hydraulic conductivity of the medium. The maximum release rate from the roof can be controlled by selecting the appropriate medium. The medium is a mechanism for “buffering” or attenuating the peak runoff rates from roofed areas. The attenuation can be important even for large storms. By using specific information about the hydraulic properties of the cover medium, the effect of the roof cover system on the runoff hydrograph can be approximated with numerical modeling techniques. As appropriate, the predicted hydrographs can be added into site-wide runoff models to evaluate the effect of the vegetative roof covers on site runoff. The hydraulic analysis of roof covers requires the services of a properly licensed design professional experienced in this type of drainage design.

Drainage nets or sheet drains with transmissivities of 15 gallons per minute per foot or higher are recommended. When assessing a drainage layer design, designers should evaluate the roof topography to establish the longest travel distances to a roof gutter, drain, or downspout. If flow converges near drains and gutters, the design unit flow rate should be increased accordingly. The drainage layer should be able to convey the design unit flow rate at the roof grade without water ponding on top of the cover medium.

For storms larger than the design storm, direct roof runoff will occur. The design flow rates should be based on the largest runoff peak attenuation considered in the design of the vegetated roof cover.

### Weight Considerations

Roof designs are dictated by state and local building codes and standards. They must account for maximum design loads contributed by dead loads, live loads, and snow or water accumulation. The design of a vegetative roof cover can alter the dead loads to the system, and it should therefore be closely coordinated with the structural design of the building. Dead loads for vegetated roof covers include the planting medium, vegetation, drainage system, and water in the pore space. However, the additional weight is partly offset by the removal of the gravel ballast.

By using appropriate materials, the total weight of fully saturated vegetated roof covers can readily be maintained below 35 pounds per square foot (psf). It is also possible that the minimum weight design focus for the vegetated roof cover might be too light to satisfy the ballast requirements for flat tar roofs. As required, deepening the medium can increase the weight of the cover system.

### Roof Gardens

Roof gardens generally are designed to achieve specific architectural objectives. The load and hydraulic requirements for roof gardens vary according to the intended use of the space. Intensive roof gardens typically include design elements such as planters filled with topsoil, decorative gravel or stone, and containers for trees and shrubs. Complete designs also may detain runoff ponding in the form of water gardens or storage in gravel beds. A wide range of hydrologic principles may be used to achieve stormwater-management objectives, including runoff peak attenuation and runoff volume control.

Effective designs ensure that all direct rainfall is cycled through one or more devices before being discharged to downspouts as runoff. For instance, rainfall collected on a raised tile patio can be directed to a medium-filled planter where some water is retained in the root zone and some is detained and gradually discharged through an overflow to the downspout.

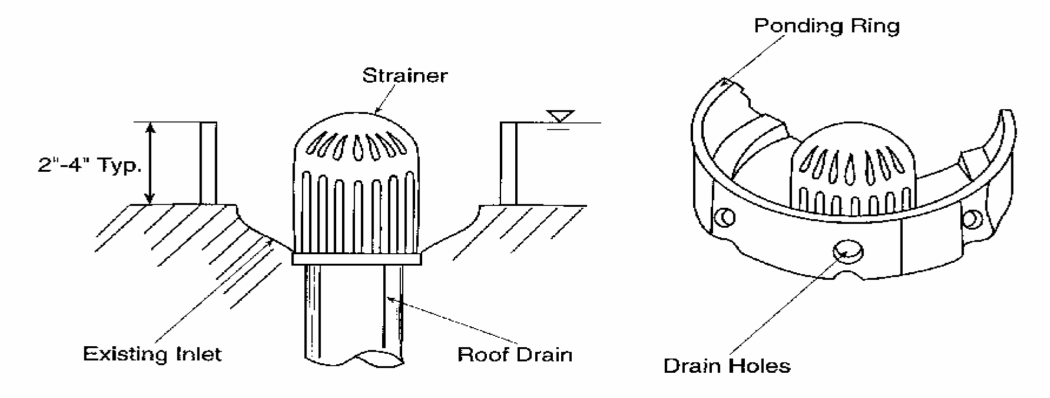
### Roof Ponding Areas

Roof ponding measures can be designed for rainfall events of all sizes. However, the structural loads associated with the impounded runoff may impose limitations on their use. This is especially true if ponding areas must also accommodate runoff derived from adjacent roof surfaces.

Flat roofs can be converted to ponding areas by restricting the flow to downspouts. Figure 2 shows a simple device that can be used to modify downspout inlets. The device features drain holes that retard outflow as the water level rises and a weir ring that allows free drainage once the design ponding level is attained. It is essential that a structural engineer verify that the existing roof can carry this extra weight. Some form of emergency overflow is advisable and can be as simple as a free overflow through a notch in the roof parapet wall.

Figure 2

Modification of Downspout Inlet (Adapted from Tourbier, 1974)




The inputs needed for analysis of roof ponding systems are similar to those needed for design of dry ponds and other runoff peak attenuation facilities. These are:

- Input hydrograph
- Depth-storage function
- Depth-discharge function

Because the roof is impermeable, the runoff hydrograph is simply the rainfall distribution for the design storm multiplied by the area of the roof.

The depth to storage relationship can be computed from the topography of the roof. For perfectly flat roofs, the storage volume of a ponding level is equal to the roof area times the ponding level.

The depth-discharge relationship is unique to the outlet device used. For simple ponding rings, the following discharge equation can be used:

$$O = 3.141\ CD(d - H)3/2$$

where:

O = outflow rate (cfs)
C = discharge coefficient (typically 3.0 but may vary depending on the shape the flow device)
D = diameter of the ring (ft)
d = depth of ponding (ft)
H = height of the ring (ft)

With this information, the attenuation effectiveness of the roof ponding system can be predicted by using the Modified Puls or other storage-routing procedure. The performance of the ponding area can be adjusted by changing the height or diameter of the ponding ring.

### Cisterns

Cisterns, or rainbarrels, are a method of collecting and storing rainwater for future use. Uses include irrigation, vehicle washing, toilet flushing, and laundry operation. Cisterns are effective for reducing runoff if they are used correctly. Cisterns must be designed to capture an appropriate volume of water that will be re-used onsite on a regular basis. Cisterns that are not used regularly will remain full, not collect rainfall from future storms, and not reduce runoff. Cistern pumps can be included in a design where an increase in water pressure is needed. Pumps should be designed to accommodate the necessary pressure and flow for the system.

## Construction and Installation

The main construction guideline is to engage professionals who are experienced with rooftop runoff management BMP installation. Preferably, the same team can undertake all phases of the project from waterproofing to planting to ensure continuity from the design to construction process.

### Additional Roof Loading

Additional loading is one of the main factors controlling the feasibility and cost of a rooftop runoff management BMP. New extensive green roofs can be accommodated in building design for a minor additional cost. Rooftop runoff management BMPs on an existing building need to consider the bearing capacity of the structure. It is also possible to use roof areas where point loading can be increased over columns or along a bearing wall, to allow areas for deeper growing medium and larger plants. A structural engineer must be consulted to verify roof and structure strength.

### Access to the Roof

Access to the roof is required for inspection and maintenance. For example, materials need to be carried to the roof for soil and plant replacements. Suitable exterior or interior access or elevator stops need to be provided to allow this access. For 1- to 3-story structures, blower trucks or shingle lifts may be used.

### Waterproof Membrane

A waterproof membrane is an essential component of a rooftop runoff management BMP. It is recommended that a membrane be installed at the same time the rooftop runoff management BMP is deployed. In addition, good drainage must be provided to prevent extended contact with water and reduce the possibility for leaks and for plant mortality due to drowning or rotting. Roof appurtenances such as parapets, skylights, mechanical systems, and vents should be well protected with a gravel skirt, and when necessary, weep drains.

If the waterproof membrane contains organic material (e.g., bitumen) plant roots may penetrate it. Also, the chemical composition of the membrane should be compatible with the surfaces with which it will be in contact. Membranes developed specifically for rooftop runoff management BMPs contain a root-deterring chemical or metal foil at the seams to prevent root damage (Peck and Kuhn, 2004).

### Horizontal Strapping

On a roof slope greater than 20 degrees, horizontal strapping or other support systems must be installed to avoid slippage and slumping of the growing medium and plants.

### Timing of Roof Planting

The timing of planting depends on the local climate and season. Planting in the summer may require additional irrigation. Fall planting depends on the availability of plants and whether there is sufficient time to allow for the plants to become established before late winter. Mid-spring planting (February–April) is recommended for much of Mississippi.

## Common Problems

Consult with qualified design professional if any of the following occur:

- Weeds are present
- Vegetation is dead or diseased
- The structure is clogged
- The structure is damaged
- Clogging has occurred
- Other damage has occurred

## Maintenance

Two to three yearly inspections are recommended to check for weeds and damage. After installation, weekly visits may be needed to ascertain the need for irrigation.

Both regular plant maintenance and maintenance of the waterproofing membrane are required. All rooftop runoff management measures must be maintained periodically. Furthermore, the vegetative measures require routine care and maintenance typical of any planted area. The maintenance includes attention to plant nutritional needs, irrigation as required during dry periods, and occasional weeding. The cost of maintenance can be significantly reduced by judiciously selecting hardy plants that will out-compete weeds. In general, fertilizers must be applied periodically. Fertilizing usually is not a problem on flat or gently sloping roofs where access is unimpeded and fertilizers can be uniformly broadcast. However, fertilization is not recommended if the roof is to be used for water quality improvement. Treading on the cover system should not damage properly designed vegetated roof covers. Maintenance contracts for routine care of the vegetative cover frequently can be negotiated with the installer.

Retrofits of existing roofs must incorporate easy access to gutters, drains, spouts, and other components of the roof drainage system. Foreign matter, including leaves and litter, should be removed promptly.

# Narrower Residential Streets

## Practice Description

This better site design practice promotes reducing the width of streets to lower the level of impervious cover associated with new residential development. By doing so, stormwater runoff and associated pollutant loads may also be reduced. Currently, many communities require residential street widths of 32, 36, and even 40 feet. Wide streets provide two parking lanes and two moving lanes, but they often provide more parking than is necessary. Narrowing street widths requires a more efficient use of the public realm and individual lots to match community needs. In many residential settings, street widths can be as narrow as 22 to 26 feet without sacrificing emergency access, on-street parking, or vehicular and pedestrian safety. Even narrower access streets can be used when only a handful of homes need to be served. Driveways make up an average of 20% of a subdivision's impervious surface, a figure which jurisdictions can reduce by allowing the use of alternative paving, shorter driveways, or even shared driveways (Schueler, 1995). Currently, developers often have little flexibility to design narrower streets because most communities require wide residential streets as a standard element of their local road and zoning standards. Revisions to current local road standards are often needed to promote greater use of narrower residential streets.

## Planning Considerations

Narrower streets can be used in residential developments generating less than 500 or fewer average daily trips (ADT). Such developments generally consist of 50 single family homes. Narrower streets may also be feasible for streets generating 500 to 1,000 ADT. However, they will not work for arterials, collectors, streets that carry greater traffic volumes, and those streets on which traffic volume varies over time.

In most communities, existing local road standards will need to be modified to allow the use of narrower streets. Several communities have successfully implemented narrower streets, including Portland, Oregon; Bucks County, Pennsylvania; and Boulder, Colorado. In addition, there are numerous examples of communities where developers have successfully narrowed private streets within innovative subdivisions. Local communities may lack the authority to change road standards when state agencies retain the review of public roads, however. In these cases, street narrowing can be accomplished only on private streets that are maintained by residents rather than by a local or state agency.

Cities interested in adopting a narrow streets policy will benefit from consulting with a broad cross section of city officials and affected stakeholders, including public works departments, emergency personnel, residential communities, and business owners, among others. Outreach and local research can help correct misperceptions about the effects of narrow streets and can gain broader acceptance for their environmental, safety and aesthetic benefits (NSPS, 2000).

## Design Criteria

Residential street design requires a balancing of competing objectives: design, speed, traffic volume, emergency access, parking, and safety. These objectives can be met in a much narrower roadway than that required by the traditional subdivision.

### Safety

Roadway widths in residential areas with 50 homes or fewer can safely be as narrow as 22 feet, according to many national engineering organizations (CWP, 1998). Narrowing streets actually lowers traffic speeds, making streets safer (USDOT, 1997). By dedicating more of the right-of-way to pedestrians and bicyclists, street planners can also make these alternative forms of travel more attractive, further reducing the number of automobile trips and relieving traffic pressure on the roadway.

### Emergency Access

Although emergency vehicle access is often given as the reason for wide roadway requirements in a subdivision, this may not be necessary. The U.S. Fire Administration indicates that a street width of 18 to 20 feet is adequate for accommodating a fire vehicle (CWP, 1998).

### Parking

The right-of-way associated with parking provides a great deal of design flexibility for reducing impermeable surface. There are some cases where on-street parking may not be desirable at all. Where the street provides space for parking, however, alternative paving surfaces, like pervious pavers, can reduce the overall impervious cover. Extending the curb and devoting some existing parking spots to stormwater management is another design alternative. Streets with angled parking accommodate this strategy well. By taking in just one or two spaces, street designers can incorporate a rain garden within the curbline at the corner or the midblock (ICF, 2009).

## Common Problems

Real and perceived barriers hinder wider acceptance of narrower streets at local levels. Advocates for narrower streets need to respond to the concerns of local agencies and the general public. Some of the more frequent concerns about narrower streets are listed below.

*Inadequate On-Street Parking*. Recent research and local experience have demonstrated that narrow streets can adequately accommodate residential parking demand. A single-family home typically requires 2 to 2.5 parking spaces. In most residential zones, this parking demand can be satisfied by one parking lane on the street and a driveway.

*Car and Pedestrian Safety*. Recent research indicates that narrow streets have lower accident rates than wide streets. Narrow streets tend to lower vehicle speeds and act as traffic-calming devices. Furthermore, sidewalk access can be provided if needed. Although this might add additional impervious area, net impervious area can be decreased due to greater reductions in street width.

*Emergency Access.* When designed properly, narrower streets can easily accommodate fire trucks, ambulances, and other emergency vehicles.

*Large Vehicles.* Field tests have shown that school buses, garbage trucks, moving vans, and other large vehicles can generally safely negotiate narrower streets, even with cars parked on both sides.

*Utility Corridors*. It is often necessary to place utilities underneath the street rather than in the right-of-way.

## Maintenance

Narrower streets should slightly reduce road maintenance costs for local communities, since they present a smaller surface area to maintain and repair.

# Riparian/Forested Buffer

Photo Source:
NRCS

## Practice Description

Riparian buffers are natural or constructed ecosystems along a shoreline, wetland, or stream where trees, grasses, shrubs, and herbaceous plants filter pollutants from stormwater runoff and shallow groundwater flow prior to discharge to receiving waters. Buffers are designed to remove sediment and other insoluble contaminants from runoff, to allow increased time for infiltration of soluble nutrients and pesticides, and to protect aquatic habitat by providing shade to watercourses to help maintain temperature norms and sound barriers to or from outside areas. Buffer zones also provide natural visual aesthetics for all land disturbance activities. Where natural buffer zones are not present or are inadequate, artificial buffer zones may be engineered using silt fences, diversions, vegetative practices and other BMPs. For additional information on Stream Protection, review the final section of Chapter 4 of Volume 1.

There are three primary types of buffers: water pollution hazard setbacks, vegetated buffers, and engineered buffers. Water pollution hazard setbacks are areas separating potential pollution hazards from waterways. Vegetated buffers are natural areas that divide land uses or provide landscape relief. Engineered buffers are specifically designed to treat stormwater before it enters streams, lakes, or wetlands.

## Planning Considerations

Buffers can be applied to new development through the establishment of specific preservation areas and by sustaining management through easements or community associations. For existing developed areas, an easement may be needed from adjoining landowners. A local ordinance can help set specific criteria for buffers to achieve stormwater management goals.

Buffer zones will vary depending on location and application. In some cases, their water quality objectives may be combined with a screening function for the noise and visual pollution of construction activities. Separate criteria will apply for various forms of land-disturbing activities:

1. Activities adjacent to a perennial stream or permanent water body
2. Silvicultural operations
3. Construction or other land-disturbing activities
4. Agricultural activities

The State of Mississippi does not require formal designs or plans for buffers except in the case of activities adjacent to a permanent water body, in which case a description of the water body, slope of adjacent land, and erodibility of soils in the area will be provided to support buffer zone width selection. If an artificial buffer zone is required, pertinent design information will be provided.

## Design Criteria

For optimal stormwater treatment, the following buffer designs are recommended. The buffer should consist of three lateral zones: a stormwater depression area leading to a grass filter strip that, in turn, leads to a forested buffer. The stormwater depression is designed to capture and store stormwater during smaller storm events and bypass larger storm flows directly into a channel. Runoff captured within the stormwater depression can then be spread across a grass filter designed for sheet flow conditions. The grass filter then discharges into a wider forest buffer designed to have zero discharge of surface runoff to the stream or full infiltration of sheet flow.

In general, a minimum width of at least 150 feet is recommended to provide adequate stream protection. The three-zone buffer system, consisting of inner, middle, and outer zones, is an effective technique for establishing a buffer. The zones are distinguished by function, width, vegetative target, and allowable uses.

- The inner zone protects physical and ecological integrity. It consists of a minimum of 25 feet plus wetland and critical habitats. The vegetative target consists of mature forest. Its allowable uses are restricted to flood controls, utility rights-of-way, footpaths, etc.
- The middle zone provides distance between upland development and the inner zone. It is typically 50 to 100 feet depending on stream order, slope, and 100-year floodplain. The vegetative target for this zone is managed forest. Usage is restricted to some recreational activities, some stormwater BMPs, and bike paths.

– The outer zone is the first zone to encounter runoff. It functions to prevent encroachment while slowing and filtering backyard runoff. The outer zone's width is at least 25 feet and, while forest is encouraged, turf-grass can be a vegetative target. The outer zone's uses are unrestricted. They can include lawn, garden, compost, yard wastes, and most stormwater BMPs ("Riparian Buffer," USEPA 2006).

# Construction and Installation

## General

Runoff from the disturbed areas should not be channeled into the buffer zone, but rather allowed to spread out over the entire buffer zone length. For concentrated flows, a level spreader may be required to allow for the proper functioning of the buffer zone.

Where a natural buffer zone is not available, or the required zone width is not attainable, provide flow barriers such as diversions, sediment traps, vegetative planting, and silt fences as needed.

## Construction or Other Land-Disturbing Activities Adjacent to a Perennial Stream or Permanent Water Body

This represents the most stringent requirement that applies to buffer zones. At a minimum, a 150′ buffer zone will be left between the land disturbance activity and a water body. The buffer zone width may be greater than 150′ depending upon the soil type and slope of adjacent land.

***Buffer Zones Adjacent to Permanent Water Bodies***

| Soil Erosion Hazard | Recommended Buffer Zone Width (Ft) (% Slope) | | |
|---|---|---|---|
| | 30 | 40 | 50 |
| Slight | | | 155 |
| Moderate | | 170 | 200 |
| Severe | 170 | 210 | 250 |

**** Refer to County Soil survey for erosion hazard. MS Forestry Commission's Mississippi BMPs Handbook states that distances should be doubled for disturbed areas in municipal watersheds.**

## Silvicultural Operations

Buffer zone requirements will adhere to the guidance provided by the Mississippi Forestry Commission (MFC) for silvicultural Best Management Practices including Streamside Management Zone and Filter Strip. For areas not adjacent to a permanent water body, a buffer zone of 15′ will be maintained on the perimeter of all silvicultural operations adjacent to property boundaries and public rights-of-way.

## Construction or other Land-Disturbing Activities

For areas not adjacent to a permanent water body, a buffer zone of 15′ will be maintained on the perimeter of the construction site. This buffer zone will:

1. Reduce runoff velocities.
2. Filter sediment from runoff.
3. Act as a screen for "vision pollution."

4. Reduce construction and adjacent noise levels.

5. Reduce dust problems.

6. Improve the aesthetics of the area.

This type of buffer zone may be crossed by construction entrances, utilities construction, etc., but where natural vegetation is removed for these purposes, artificial buffer zone measures should be installed (e.g. construction entrance BMP, silt fence, diversion, etc.).

These post-construction measures should be incorporated into the design of the final post-construction landscape providing a permanent green strip on the perimeter of the completed project.

## Common Problems

The table below describes some common obstacles to the best performance of riparian buffers at removing pollutants from stormwater and the design factors that can enhance their performance.

**Factors that Enhance/Reduce Buffer Pollutant Removal Performance**
(“Riparian Buffers,” USEPA 2006)

| Factors that Enhance Performance | Factors that Reduce Performance |
|---|---|
| Slopes less than 5% | Slopes greater than 5% |
| Contributing flow lengths <150 feet. | Overland flow paths over 300 feet |
| Water table close to surface | Ground water far below surface |
| Check dams/level spreaders | Contact times less than 5 minutes |
| Permeable but not sandy soils | Compacted soils |
| Growing season | Non-growing season |
| Long length of buffer or swale | Buffers less than 10 feet |
| Organic matter, humus, or mulch layer | Snowmelt conditions, ice cover |
| Small runoff events | Runoff events >2 year event. |
| Entry runoff velocity less than 1.5 feet/sec | Entry runoff velocity more than 5 feet/sec |
| Swales that are routinely mowed | Sediment buildup at top of swale |
| Poorly drained soils, deep roots | Trees with shallow root systems |
| Dense grass cover, 6 inches tall | Tall grass, sparse vegetative cover |

## Maintenance

An effective buffer-management plan offers many aesthetic, environmental, and recreational benefits but must be adequately managed to function properly. The initial design should include establishment, management, and distinctions of allowable and prohibited uses in the buffer zones. Buffer boundaries should be well defined and visible before, during, and after construction. Without clear signs or markers defining the buffer, its boundaries can become invisible to local governments, contractors, and residents. In some cases, these sites may even be used as dumping grounds for those unaware of their purpose of protecting water quality. Regular clean-up and landscape maintenance will ensure that riparian buffers remain an asset to the community and build public support for the continued use of riparian buffers as a stormwater management practice (NCDENR, 2007). Particular attention must be paid to buffers designed to capture urban stormwater runoff. These sites will require more maintenance if the first zone is designated as a bioretention or other engineered depression area ("Riparian Buffer," USEPA 2006).

# Grassed Swales

## Practice Description

In the context of BMPs to improve water quality, the term swale (a.k.a. grassed channel, dry swale, wet swale, biofilter, or bioswale) refers to vegetated, open-channel management practices designed specifically to treat and attenuate stormwater runoff for a specified water quality volume. Swales remove pollutants from stormwater by biofiltration, settling, and infiltration. Grassed swales filter pollutants as stormwater runoff moves through the leaves and roots of the grass. By reducing flow velocities and increasing a site's time of concentration, grassed swales contribute to reducing runoff peaks. Grassed swales that are designed with check dams or incorporate depression storage promote infiltration and can help contribute to satisfying a site runoff capture/storage requirement.

Variations of the grassed swale include the grassed channel, dry swale, and wet swale. The specific design features and methods of treatment differ in each of these designs, but all are improvements on the traditional drainage ditch. These designs incorporate modified geometry and other features for use of the swale as a treatment and conveyance practice.

## Planning Considerations

Grassed swales can be applied in most situations with some restrictions. Swales are well suited for treating highway or residential road runoff because they are linear practices. Swales are also useful as one of a series of stormwater BMPs or as part of a treatment train, for instance, conveying water to a detention pond and receiving water from filter strips. Furthermore, swales are highly recommended by the proponents of design approaches such as Low Impact Development and Better Site Design.

The use of grassed swales in new development can be a cost-effective alternative to curb and gutter installation. The swale practices are considered more aesthetically pleasing, although there is the potential for standing water and possible mosquito infestations.

The effectiveness of a swale in both reducing the flow rates and volume of runoff, and removing pollutants, is a function of the size and composition of the drainage area, the slope and cross section of the channel, the permeability of the soil, the density and type of vegetation in the swales, and the swale dimensions. Broad swales on flat slopes with dense vegetation are the most effective. Removal efficiencies are highest for sediment-bound pollutants.

# Design Criteria

In addition to the broad applicability concerns described above, designers need to consider site conditions. In addition, they need to incorporate design features to improve the longevity and performance of the practice while minimizing the maintenance burden.

## Converting Erosion- and Sediment-Control Devices

Swales are often used as erosion- and sediment-sediment control measures during active construction. The same swales can later be used as grassed swale BMPs; however, all of the sediment must be removed, the channel configuration and slope must be re-established (if necessary), and the proper vegetation must be established. See the Grass Swale practice under Runoff Conveyance in Chapter 4 of Volume 1 of this Manual for more information on grass swales as erosion- and sediment-control devices.

## Siting Considerations

In addition to considering the restrictions and adaptations of grassed swales to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question because some site conditions (i.e., steep slopes, highly impermeable soils) might restrict the effectiveness of grassed channels.

### Drainage Area

Grassed swales should generally treat runoff from small drainage areas (less than 5 acres). If used to treat larger areas, the flows through the swale become too large to produce designs to treat stormwater runoff in addition to conveyance.

### Capacity

The capacity of the swale must also be checked to ensure that it will be adequate after vegetation is fully established. The resistance to flow should be evaluated using the NRCS retardance factor for the vegetation selected (consult *Grass Swale* in Chapter 4 of Volume 1).

The flow depth of the design event should be evaluated using Manning's equation for the swale type used (parabolic, trapezoidal, or V-shaped). The design requirement is that the swales convey the design discharge while maintaining a 0.5-foot freeboard and without exceeding the maximum permissible velocity.

If driveways or roads cross the swale, the capacity of the culvert crossing the road or driveway may determine the depth of flow for the design event. In these instances, the culverts should be checked to establish that the backwater elevation does not exceed the banks of the swale. If the culvert discharges to a minimum tailwater condition, the exit velocity for the culvert should be evaluated for design conditions. If the maximum permissible velocity is exceeded at the culvert outlet, riprap or another measure to prevent scour must be used.

### Slope

Grassed swales should be used on sites with relatively flat slopes of less than 4 percent slope; 1 to 2 percent slope is recommended. When site conditions require installing the swales in areas with larger slopes, check dams can be used to reduce the influence of the slope. Runoff velocities within the channel become too high on steeper slopes. This can cause erosion and does not allow for infiltration or filtering in the swale.

### Soils/Topography

Grassed swales can be used on most soils, with some restrictions on the most impermeable soils. In the dry swale (see Design Variations section below), a fabricated soil bed replaces on-site soils in order to ensure that runoff is filtered as it travels through the soils of the swale.

### Groundwater

The required depth to groundwater depends on the type of swale used. In the dry swale and grassed channel options, the bottom of the swale should be constructed at least 2 feet above the groundwater table to prevent a moist swale bottom or contamination of the groundwater. In the wet swale option, treatment is provided by creating a standing or slow-flowing wet pool, which is maintained by intersecting the groundwater.

## Design Considerations

Although there are different design variations of the grassed swale (see Design Variations), some design considerations are common to all designs. An overriding similarity is the cross-sectional geometry. Swales often have a trapezoidal or parabolic cross section with relatively flat side slopes (flatter than 3:1), though rectangular and triangular channels can also be used. Designing the channel with flat side slopes increases the wetted perimeter. The wetted perimeter is the length along the edge of the swale cross section where runoff flowing through the swale contacts the vegetated sides and bottom. Increasing the wetted perimeter slows runoff velocities and provides more contact with vegetation to encourage sorption, filtering, and infiltration. Another advantage to flat side slopes is that runoff entering the grassed swale from the side receives some pretreatment along the side slope.

Another similarity among designs is the type of pretreatment needed. In all design options, a small forebay should be used at the front of the swale to trap incoming sediments. A pea gravel diaphragm, a small trench filled with river-run gravel, should be constructed along the length of the swale and used as pretreatment for runoff entering the sides of the swale. Other features designed to enhance the performance of grassed swales are a flat longitudinal slope (generally between 1 percent and 2 percent) and a dense vegetative cover in the channel. The flat slope helps to reduce the flow velocity within the channel. The dense vegetation also helps reduce velocities, protects the channel from erosion, and acts as a filter to treat stormwater runoff. During construction, it is important to stabilize the channel while the vegetation is becoming established, either with a temporary grass cover or with natural or synthetic erosion-control products. In addition to treating runoff for water quality, grassed swales must convey runoff from larger storms safely. Typical designs allow the runoff from the 2-year storm (i.e., the storm that occurs, on average, once every two years) to flow through the swale without causing erosion. Swales should also have the capacity to pass larger storms (typically a 10-year storm) safely.

### Ponding and Infiltration

Ponding can be beneficial if intended and accepted, or it can be a negative if unintended. If unintended and not designed for, extended periods of standing water may result in nuisance conditions and create complaints from residents. Mosquitoes are typically the biggest concern; however, they should generally not be a problem because of the frequent flushing of the ponded water. Also, if wetland vegetation develops, mosquito predators such as other insects and birds often mitigate the mosquito problem. If wetland vegetation and standing water are persistent concerns, these problems can be reduced by maintaining more uniform, steeper slopes in the swale invert or by installing underdrains.

If temporary retention of small amounts of water is desired for enhanced treatment of the stormwater and ecological and visual diversity, there are many ways to achieve that goal. The paragraphs below discuss several methods for retaining water or otherwise modifying the typical swale hydrology. The retained water will infiltrate, be lost through evapotranspiration, or slowly released downstream. It should be noted that the maximum allowable ponding time within a channel is 48 hours, and an underdrain system must be provided if that requirement cannot be met.

### Check Dams

A check dam is constructed of earth, stone, or timber 3 to 6 inches high to retain runoff from routine events. A weep hole may be added to enable the area behind an earthen or timber dam to drain slowly. However, the weep hole may be subject to clogging. Shorter check dams can act as level spreaders to help distribute the flow along the swale's cross section.

### Elevated Drop Inlets

A drop inlet can be used when a combined system of swales and storm sewers is being used. The swales would serve as the collector system, and the inlet into the main storm sewer system would be elevated slightly to retain runoff from routine events. The height of elevation would depend on the soil, the slope of the swale, and the tolerance for ponding. Wetland vegetation may develop in the ponded areas if the underlying soils are poorly drained.

### Elevated Culverts

Elevated culverts are used for the same purpose as check dams and elevated drop inlets, to retain runoff from routine events. As with elevated drop inlets, wetland vegetation may develop in the ponded areas if the underlying soils are poorly drained.

### Depression Storage

Small depressions along the bottom of the swale will trap and store stormwater for later infiltration into the soils. These depressions will also likely accumulate sediment at a quicker pace than other parts of the swale, and will also probably develop wetland vegetation.

### Underdrains

Underdrains can enhance the performance of swales by providing additional filtration through soil, similar to the process that takes place in bioretention facilities. These "bioretention" swales have a layer of engineered soil underlain by a gravel layer surrounding a perforated pipe. This configuration also reduces ponding time where standing water may be a concern.

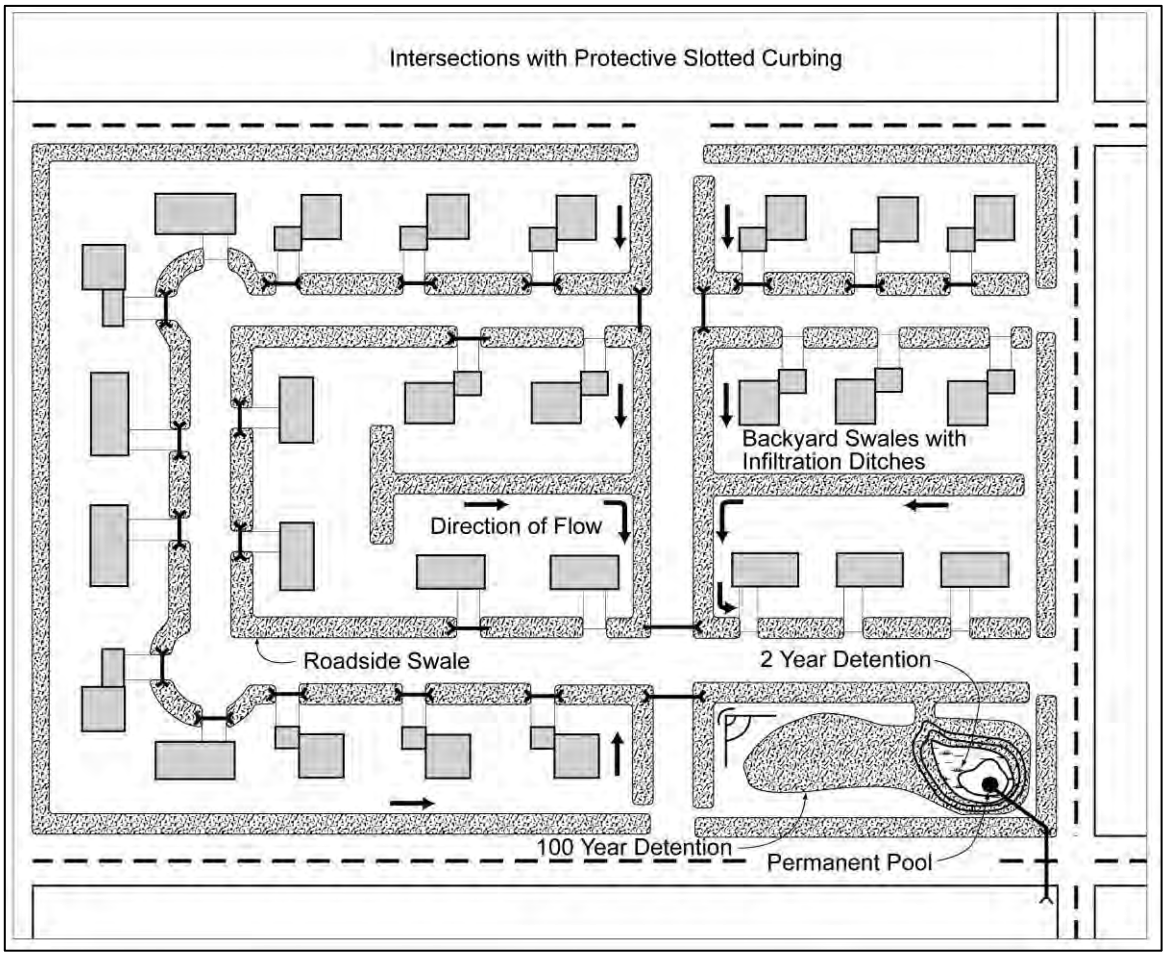



Figure 1 Schematic of Plan for Retrofit of Grassed Swales in Residential Subdivision

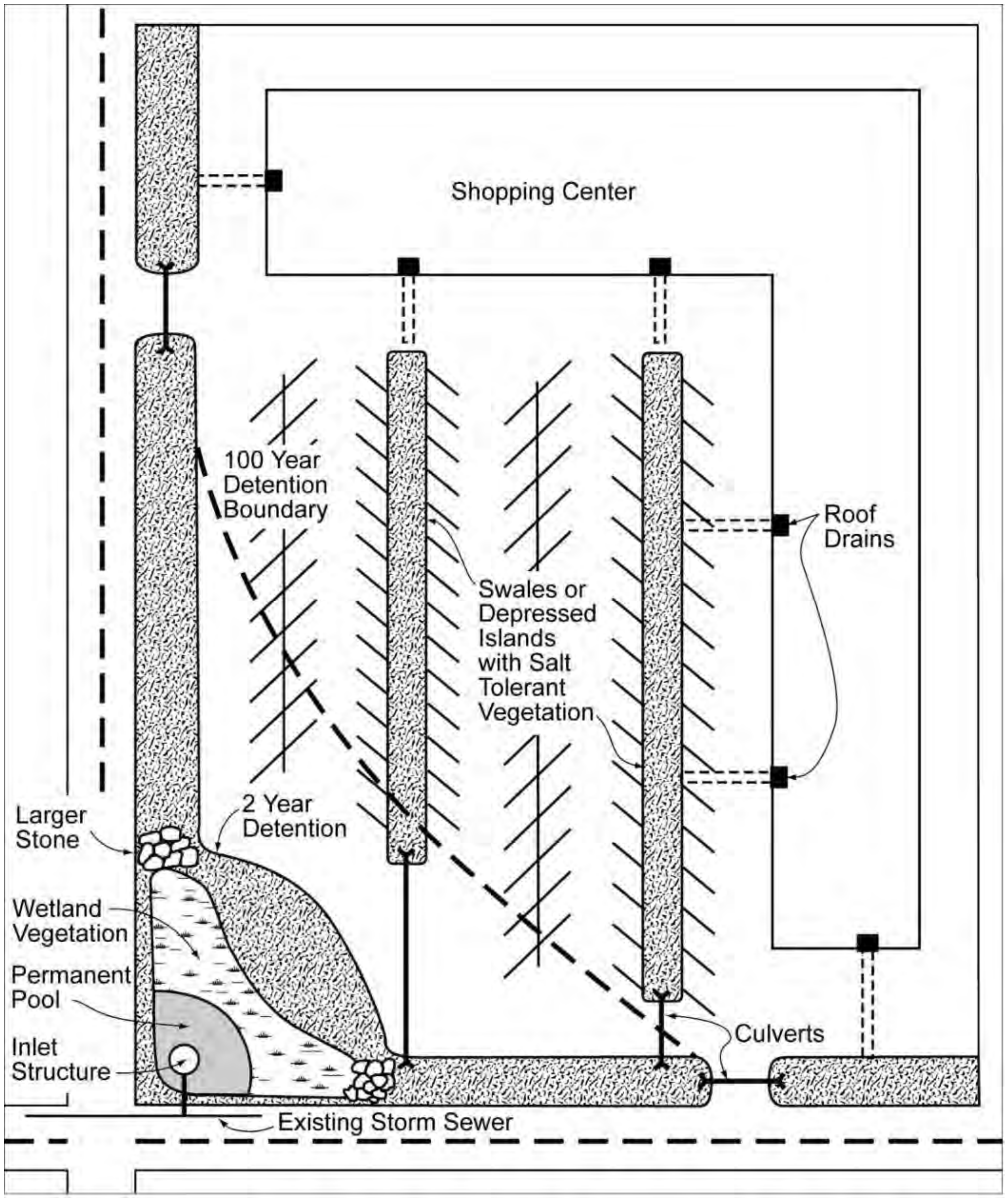



Figure 2 Example of Grassed Swale Used for Parking Lot

## Design Variations

The following discussion identifies three variations of open-channel practices—the grassed channel, dry swale, and wet swale.

### Grassed Channel

Of the three grassed swale designs, grassed channels are the most similar to a conventional drainage ditch, with the major differences being flatter side slopes and longitudinal slopes, and a slower design velocity for water quality treatment of small storm events. Of all of the options, grassed channels are the least expensive but also provide the least reliable pollutant removal. An excellent application of a grassed channel is as pretreatment to other structural stormwater practices. A major difference between the grassed channel and many other structural practices is the method used to size the practice. Most stormwater-management water quality practices are sized by volume. This method sets the volume available in the practice equal to the water quality volume, or the volume of water to be treated in the practice. The grassed channel is a flow rate-based design. Based on the peak flow from the water quality storm, the channel should be designed so that runoff takes, on average, 10 minutes to flow from the top to the bottom of the channel. A procedure for this design can be found in *Design of Stormwater Filtering Systems* (CWP, 1996).

### Dry Swales

Dry swales are similar in design to bioretention areas (see *Bioretention Practice*). These designs incorporate a fabricated soil bed into their design. The native soil is replaced with a sand/soil mix that meets minimum permeability requirements. An underdrain system is installed at the bottom of the soil bed. This underdrain is a gravel layer that encases a perforated pipe. Stormwater treated in the soil bed flows into the underdrain, which routes this treated stormwater to the storm drain system or receiving waters. Dry swales are a relatively new design, but studies of swales with a native soil similar to the man-made soil bed of dry swales suggest high pollutant removal.

### Wet Swales

Wet swales intersect the groundwater and behave similarly to a linear wetland cell (see *Constructed Stormwater Wetland Practice*). This design variation incorporates a shallow permanent pool and wetland vegetation to provide stormwater treatment. This design also has potentially high pollutant removal. Wet swales are not commonly used in residential or commercial settings because the shallow standing water may be a potential mosquito breeding area.

# Construction Considerations

To maximize the infiltration capacity of the swale, compaction of the soil underlying the swale should be avoided. For example, equipment for excavating or grading should operate from the side of the swale instead of the bottom of the swale.

Before vegetation is established in a swale, the swale is particularly vulnerable to scour and erosion. Therefore, protecting the seedbed with a temporary erosion-resistant lining (such as a geosynthetic or fiberglass roving) or other suitable erosion controls is generally necessary. Most vendors will furnish information about the Manning's coefficient (*n*) and will also specify the maximum permissible velocity or allowable unit tractive force (also referred to as the "tractive stress") for the lining material. Swales should be constructed and vegetated early in the construction schedule, preferably before area grading and paving increase the rate of runoff.

Temporary erosion-resistant channel linings should be used to stabilize the swale until the vegetation becomes established. The vendor's instructions for installing channel linings should be followed. If velocities will be high, designers should consider sodding the swale or diverting runoff until vegetation is established.

## Common Problems

Grassed swales are relatively low-maintenance BMPs, but some potential problems include the following:

- Ponded water makes swale difficult to mow, and can cause nuisance problems such as odors, discoloration, and mosquitoes.
- Erosion due to improper vegetation establishment.
- Sediment accumulation due to inadequate erosion-control upstream.

## Maintenance

Routine maintenance of grassed swales will include the removal of trash and debris.

If bare soil or signs of erosion are evident, regrade the soil to remove gully erosion and then re-sod and water until established.

Sediment should be removed if it accumulates within the swale.

# Infiltration Basin

## Practice Description

An infiltration basin is a shallow impoundment that is designed to infiltrate stormwater into the soil. This practice is believed to have a high pollutant-removal efficiency and can also help recharge the groundwater, thus increasing baseflow to stream systems. Infiltration basins can be challenging to apply on many sites, however, because of soils requirements. In addition, some studies have shown relatively high failure rates compared with other management practices.

## Planning Considerations

Infiltration basins have select applications. Their use is often sharply restricted by concerns over groundwater contamination, soils, and clogging at the site. They work best in relatively small drainage areas and in drainage areas that are completely impervious or stable (to minimize the amount of sediment going to the BMP). Infiltration basins are frequently used to infiltrate runoff from adjacent impervious surfaces, such as parking lots. In these cases, a filter strip should be installed between the pavement and the device to trap sediment and litter before it is washed into the device. Another approach is to construct infiltration devices at the downgradient edges of areas with permeable pavement. In this case, the permeable pavement is the inlet to the device. Because water also will infiltrate through the base of the pavement, the size of the infiltration devices can be reduced significantly.

## Design Considerations

When designing infiltration basins, designers need to carefully consider both the restrictions on the site and design features to improve the long-term performance of the practice.

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most infiltration basin designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, outlet, and landscaping.

### Pretreatment

Pretreatment devices for removing sediment and solids must be used to protect infiltration devices from clogging. A few options for pretreatment include filter strips, grassed swales with check dams, concrete sumps, and forebays (sediment traps).

Consideration should be given to the inlet when infiltration facilities are designed. The type of inlet will depend on whether the upgradient source of runoff is overland flow or a concentrated source of discharge. Infiltration trenches require relatively even distribution over their length. An infiltration basin can be designed to accommodate a concentrated influent flow; however, an energy dissipater and/or level spreader may be needed.

### Treatment

Treatment design features enhance the pollutant removal of a practice. For infiltration practices, designers need to stabilize upland soils to ensure that the basin does not become clogged with sediment. In addition, the facility needs to be sized so that the volume of water to be treated infiltrates through the bottom in a given amount of time. Because infiltration basins are designed in this manner, infiltration basins designed on less permeable soils should be significantly larger than those designed on more permeable soils.

### Conveyance

Stormwater needs to be conveyed through stormwater-management practices safely and in a way that minimizes erosion. Designers need to be particularly careful in ensuring that channels leading to an infiltration practice are designed to minimize erosion. In general, infiltration basins should be designed to treat only small storms (i.e., only for water quality). Thus, these practices should be designed “off-line,” using a flow separator to divert only small flows to the practice.

### Outlet Design

Infiltration devices, by their very nature, do not have regular outlet devices. (The stormwater entering the BMP leaves through the soils.) They should, however, be designed with dewatering provisions in the event of failure. It can be dewatered by pumping out or allowed to gravity-drain through a pipe. If a dewatering outlet pipe is installed to facilitate emergency draining, a lockable watertight valve must be installed and kept closed at all times.

### Landscaping

Landscaping can enhance the aesthetic value of stormwater practices or improve their function. In infiltration basins, the most important purpose of vegetation is to reduce the tendency of the practice to clog. Upland drainage needs to be properly stabilized with a thick layer of vegetation, particularly immediately following construction. In addition, providing a thick turf at the basin bottom helps encourage infiltration and prevent the formation of rills in the basin bottom.

# Siting Considerations

Infiltration practices need to be located extremely carefully. In particular, designers need to ensure that the soils on the site are appropriate for infiltration, and that designs minimize the potential for groundwater contamination and long-term maintenance problems.

## Converting Erosion- and Sediment-Control Devices

Often, the same basin can be used during construction as an erosion- and sediment-control device and later converted to an infiltration basin. Before conversion, all accumulated sediment must be removed and properly disposed of. Then, the appropriate modifications to the basin depth, geometry, and hydrology, as well as inlet and outlet structures, etc., must be made. A minimum of 6 inches of bottom material (below the design bottom of the original sediment and erosion control device) must be removed prior to conversion to a stormwater BMP, so appropriate design bottom depth changes must be considered. It is essential that the site be completely stabilized before the erosion- and sediment-control devices are removed or converted.

### Drainage Area

Infiltration basins have historically been used as regional facilities, serving for both water-quantity and water-quality control. In general, the practice is best applied to relatively small drainage areas (i.e., less than 10 acres).

### Slope

The bottom of an infiltration basin needs to be completely flat to allow infiltration throughout the entire basin bottom.

### Soils/Topography

Soils and topography are strongly limiting factors when locating infiltration practices. Soils must be significantly permeable to ensure that the practice can infiltrate quickly enough to reduce the potential for clogging. Soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for groundwater contamination. A *site-specific* hydrogeologic investigation shall be performed to establish the suitability of site soils for the BMP. To be suitable for infiltration, underlying soils must have an infiltration rate of 0.52 inch per hour or greater, as initially determined from NRCS soil textural classification (typically hydrologic soil groups A and B) and subsequently confirmed by field geotechnical tests.

### Groundwater

Designers always need to provide significant separation distance (2 to 5 feet) from the bottom of the infiltration basin and the seasonally high groundwater table, to reduce the risk of contamination. Infiltration practices should also be separated from drinking water wells.

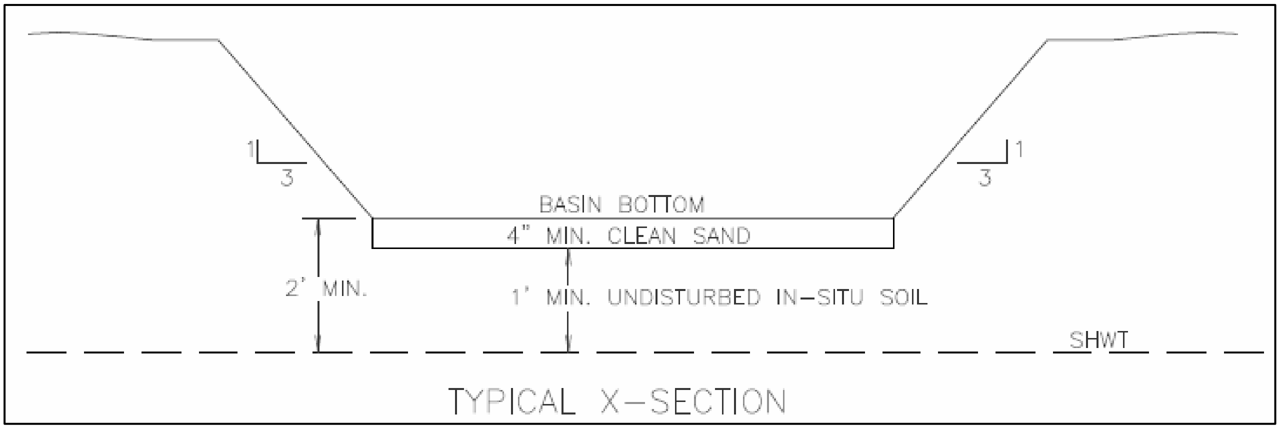



Figure 1 Typical Infiltration Basin: Cross Section
(Note: Retaining walls may be used in place of 3:1 vegetated side slopes)

## Construction Considerations

Care should be used during installation to minimize compaction of soil on the bottom and walls of infiltration devices, since this will reduce the permeability at the soil interface. To avoid compacting the drainage media, lighter weight equipment and construction techniques that minimize compaction should be used.

Runoff shall not be directed into an infiltration device until the drainage area is stabilized. A construction sequence must be followed that reflects the need to stabilize the infiltration device. The longevity of infiltration devices is strongly influenced by the care taken during construction.

A minimum of one observation well shall be included in the design of an infiltration system to periodically verify that the drainage media are fully draining. The monitoring well shall consist of a 4- to 6-inch-diameter, perforated polyvinyl chloride (PVC) pipe with a locking cap. The well should be placed near the center of the facility or in the general location of the lowest point within the facility, with the invert at the excavated bottom of the facility.

### Length, Width, Depth and Geometry

The sizing of an infiltration device is determined by the dewatering requirements. Infiltration devices must be able to completely dewater within 5 days. The time to dewater can be estimated roughly as the runoff capture volume for the device divided by the product of the hydraulic conductivity and the effective infiltrating area. This can be rearranged to produce the following equation for determining the effective infiltrating area needed:

$$A = \frac{V}{2 * (K * T)}$$

where:

A = effective infiltrating area ($ft^2$)
V = volume of water requiring infiltration ($ft^3$)
K = hydraulic conductivity of soil (in/hr)
T = dewatering time (days)

The volume of water requiring infiltration (V) is prescribed by the specific stormwater program that applies to the site, and the runoff characteristics of the site. If the infiltration device is not going to meet the volume control requirements, it is simply the volume of water that is diverted and stored for infiltration. The runoff capture storage volume of an infiltration device that is filled with a drainage medium is equal to the volume of the facility, multiplied by the porosity of the medium, plus any temporary ponding that may be allowed before the facility overflows.

The hydraulic conductivity of the soil (K) is the resultant value from the field testing performed on the site. The dewatering time (T) for infiltration devices must be 5 days or less. A value of less than 3 days is recommended for use in the formula.

Once the effective infiltrating area (A) is obtained from the formula, it can still be somewhat difficult to translate that into actual infiltration device dimensions. The value for A used in the formula is actually the larger of either the bottom surface area or one-half of the total (wetted) wall area. The determination of the length, width, and depth dimensions is therefore often an iterative process using the effective infiltrating area (A); the correction factor for true surface areas of the in situ soil interface; and typical length, width, and depth recommendations.

Infiltration basins may appear in a variety of geometries. Runoff frequently is piped to these devices from stormwater inlets on patios, parking areas, roofs, and other impervious areas. These devices may also receive runoff via sheet flow.

## Common Problems

Although infiltration basins can be useful practices, they have several limitations. Infiltration basins are not generally aesthetic practices, particularly if they clog. If infiltration basins are designed and maintained so that standing water is left for no more than 3 days, mosquitoes should not be a problem. However, if an infiltration basin becomes clogged and takes 4 or more days to drain, the basin could become a source for mosquitoes. In addition, these practices are challenging to apply because of concerns over groundwater contamination and sufficient soil infiltration. Finally, maintenance of infiltration practices can be burdensome, and they have a relatively high rate of failure.

## Maintenance

Regular maintenance is critical to the successful operation of infiltration basins.

Immediately after the infiltration basin is established, the vegetation will be watered twice weekly if needed until the plants become established (commonly six weeks).

No portion of the infiltration basin will be fertilized after the initial fertilization that is required to establish the vegetation.

If areas of bare soil and/or erosive gullies form, regrade the soil to remove the gully, plant a ground cover, and water until it has established.

The vegetation in and around the basin will be maintained at a height of approximately six inches.

Should sediment accumulation reach 75% of the original design depth, the source of sediment should be identified and remedied. The sediment shall be removed and the basin restored to original design specifics.

# Infiltration Trench

## Practice Description

An infiltration trench (a.k.a. infiltration galley) is a rock-filled trench with no outlet that receives stormwater runoff. Stormwater runoff passes through some combination of pretreatment measures, such as a swale and detention basin, and into the trench. There, runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix. The primary pollutant removal mechanism of this practice is filtering through the soil.

## Planning Considerations

Infiltration trenches have select applications. Although they can be applied in a variety of situations, the use of infiltration trenches is restricted by concerns over groundwater contamination, soils, and clogging.

Infiltration trenches are frequently used to infiltrate runoff from adjacent impervious surfaces, such as parking lots. In these cases, a filter strip should be installed between the pavement and the device to trap sediment and litter before they are washed into the device. Another approach is to construct infiltration trenches at the downgradient edges of areas with permeable pavement. In this case, the permeable pavement is the inlet to the device. Because water also will infiltrate through the base of the pavement, the size of the infiltration devices can be reduced significantly.

## Design Criteria

Infiltration trenches are filled with large crushed stone or other media to create storage for the stormwater in the voids between the media. Other versions use precast concrete vaults with open bottoms to provide a large storage volume to hold stormwater for infiltration into the soil. Infiltration trenches are usually used to manage the runoff from parking lots and buildings.

### Converting Erosion- and Sediment-Control Devices

Infiltration trenches shall not be used as sediment- and erosion-control devices.

### Siting Considerations

Infiltration practices need to be sited extremely carefully. In particular, designers need to ensure that the soils on site are appropriate for infiltration and that designs minimize the potential for groundwater contamination and long-term maintenance.

#### Drainage Area

Infiltration trenches generally can be applied to relatively small sites (less than 5 acres), with relatively high impervious cover. Application to larger sites generally causes clogging, resulting in a high maintenance burden.

#### Slope

Infiltration trenches should be placed on flat ground, but the slopes of the site draining to the practice can be as steep as 15 percent.

#### Soils/Topography

Soils and topography are strongly limiting factors when locating infiltration practices. Soils must be significantly permeable to ensure that the stormwater can infiltrate quickly enough to reduce the potential for clogging. In addition, soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for groundwater contamination. To be suitable for infiltration, underlying soils must have an infiltration rate of 0.52 inch per hour or greater, as initially determined from NRCS soil textural classification (typically hydrologic soil groups A and B) and subsequently confirmed by field geotechnical tests. The infiltration rate and textural class of the soil need to be confirmed in the field; designers should not rely on more generic information such as a soil survey. Finally, infiltration trenches may not be used in regions of karst topography, due to the potential for sinkhole formation or groundwater contamination.

#### Groundwater

Designers always need to provide significant separation (2 to 5 feet) from the bottom of the infiltration trench and the seasonally high groundwater table, to reduce the risk of contamination. In addition, infiltration practices should be separated from drinking water wells.

## Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most infiltration trench designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

### Pretreatment

Pretreatment refers to design features that provide settling of large particles before runoff reaches a management practice, easing the long-term maintenance burden. Pretreatment is important for all structural stormwater-management practices, but it is particularly important for infiltration practices. To ensure that pretreatment mechanisms are effective, designers should incorporate "multiple pretreatment," using practices such as grassed swales, vegetated filter strips, detention, or a plunge pool in series.

### Treatment

Treatment design features enhance the pollutant removal of a practice. During the construction process, the upland soils of infiltration trenches need to be stabilized to ensure that the trench does not become clogged with sediment. Furthermore, the practice should be filled with large clean stones that can retain the volume of water to be treated in their voids. Like infiltration basins, this practice should be sized so that the volume to be treated can infiltrate out of the trench bottom in 24 hours.

### Conveyance

Stormwater needs to be conveyed through stormwater management practices safely, and in a way that minimizes erosion. Designers need to be particularly careful in ensuring that channels leading to an infiltration practice are designed to minimize erosion. Infiltration trenches should be designed to treat only small storms, (i.e., only for water quality). Thus, these practices should be designed "off-line," using a structure to divert only small flows to the practice. Finally, the sides of an infiltration trench should be lined with a geotextile fabric to prevent flow from causing rills along the edge of the practice.

### Maintenance Reduction

In addition to regular maintenance activities, designers also need to incorporate features into the design to ensure that the maintenance burden of a practice is reduced. These features can make regular maintenance activities easier or reduce the need to perform maintenance. As with all management practices, infiltration trenches should have an access path for maintenance activities. An observation well (i.e., a perforated PVC pipe that leads to the bottom of the trench) can enable inspectors to monitor the drawdown rate. Where possible, trenches should have a means to drain the practice if it becomes clogged, such as an underdrain. An underdrain is a perforated pipe system in a gravel bed, on the bottom of filtering practices, installed to collect and remove filtered runoff. An underdrain pipe with a shutoff valve can be used in an infiltration system to act as an overflow in case of clogging.

### Landscaping

In infiltration trenches, there is no landscaping on the practice itself, but it is important to ensure that the upland drainage is properly stabilized with thick vegetation, particularly following construction.

### Length, Width, Depth and Geometry

The sizing of an infiltration device is determined by the dewatering requirements. Infiltration devices must be able to completely dewater within 5 days. The time to dewater can be estimated roughly as the runoff capture volume for the device divided by the product of the hydraulic conductivity and the effective infiltrating area. This can be rearranged to produce the following equation for determining the effective infiltrating area needed:

$$A = \frac{V}{2 * (K * T)}$$

where:

A = effective infiltrating area ($ft^2$)
V = volume of water requiring infiltration ($ft^3$)
K = hydraulic conductivity of soil (in/hr)
T = dewatering time (days)

The volume of water requiring infiltration (V) is prescribed by the specific stormwater program that applies to the site, and the runoff characteristics of the site. If the infiltration device is not going to meet the volume control requirements, it is simply the volume of water that is diverted and stored for infiltration. The runoff capture storage volume of an infiltration device that is filled with a drainage medium is equal to the volume of the facility, multiplied by the porosity of the medium, plus any temporary ponding that may be allowed before the facility overflows.

The hydraulic conductivity of the soil (K) is the resultant value from the field testing performed on the site. The dewatering time (T) for infiltration devices must be 5 days or less. A value of less than 3 days is recommended for use in the formula.

Once the effective infiltrating area (A) is obtained from the formula, it can still be somewhat difficult to translate that into actual infiltration device dimensions. The value for A used in the formula is actually the larger of either the bottom surface area or one-half of the total (wetted) wall area. The determination of the length, width, and depth dimensions is therefore often an iterative process using the effective infiltrating area (A); the correction factor for true surface areas of the in situ soil interface; and typical length, width, and depth recommendations.

Trench depths shall be no more than 8 feet. It is recommended that the width of a trench (perpendicular to influent flow direction) be less than 25 feet. Broad, shallow trenches reduce the risk of clogging by spreading the runoff over a larger area for infiltration.

## Construction Considerations

Care should be used during installation to minimize compaction of soil on the bottom and walls of infiltration devices, since this will reduce the permeability at the soil interface. To avoid compacting the drainage media, lighter weight equipment and construction techniques that minimize compaction should be used.

Runoff shall not be directed into an infiltration device until the drainage area is stabilized. A construction sequence must be followed that reflects the need to stabilize the infiltration device. The longevity of infiltration devices is strongly influenced by the care taken during construction.

Infiltration trenches should not be covered by an impermeable surface unless there is suitable maintenance access, the design specifies an H-20 loading capacity, and the application includes a cross section of the H-20 design. Direct access must be provided to all infiltration devices for maintenance and rehabilitation. OSHA safety standards should be consulted for trench excavation.

A minimum of one observation well shall be included in the design of an infiltration system to periodically verify that the drainage media are fully draining. The monitoring well shall consist of a 4- to 6-inch-diameter, perforated polyvinyl chloride (PVC) pipe with a locking cap. The well should be placed near the center of the facility or in the general location of the lowest point within the facility, with the invert at the excavated bottom of the facility.

## Common Problems

Although infiltration trenches can be a useful management practice, they have several limitations. While they do not detract visually from a site, infiltration trenches provide no visual enhancements. Their application is limited due to concerns over groundwater contamination and other soils requirements. Finally, maintenance can be burdensome, and infiltration practices have a relatively high rate of failure.

## Maintenance

Regular maintenance of infiltration trenches is needed to reduce the likelihood of BMP failure.

If grass filter strips are present, they should be monitored for areas of bare soil and/or erosive gullies. These items should be repaired immediately by re-grading the area and re-planting. The planted area should be protected using mulching until vegetation can be established.

Sediment accumulation can clog the filter strip, the flow diversion structure, or the trench itself. First, the source of the sediment should be identified and the erosion issues addressed. Then, the sediment should be removed and the device restored to initial design standards.

# Permeable Interlocking Concrete Paving

## Practice Description

Permeable interlocking concrete paving (PICP) consists of manufactured concrete units that reduce stormwater-runoff volume, rate, and pollutants. The impervious units are designed with small openings between permeable joints. The openings typically comprise 5% to 15% of the paver surface area and are filled with highly permeable, small-sized aggregates. The joints allow stormwater to enter a crushed stone aggregate bedding layer and base that supports the pavers, while providing storage and runoff treatment. PICPs are highly attractive, durable, and easily repaired; require low maintenance; and can withstand heavy vehicle loads.

## Planning Considerations

PICP can replace traditional impervious pavement for most pedestrian and vehicular applications except high-volume/high-speed roadways. PICP has performed successfully in pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways. The environmental benefits from PICP allow it to be incorporated into municipal green infrastructure and low impact development programs. In addition to providing stormwater volume and quality management, light-colored pavers are cooler than conventional asphalt and help to reduce urban temperatures and improve air quality. The textured surface of PICP also provides traffic calming and provides an aesthetic amenity.

PICP should not be confused with concrete grid pavements (i.e., concrete units with cells that typically contain topsoil and grass). These paving units can infiltrate water, but at rates lower than PICP. Unlike PICP, concrete grid pavements are generally not designed with an open-graded, crushed stone base for water storage. Moreover, grids are for intermittently trafficked areas such as overflow parking areas and emergency fire lanes.

## Design Criteria

PICP should be designed and sited to intercept, contain, filter, and infiltrate stormwater on site. Several design possibilities can achieve these design aspects. For example, PICP can be installed across an entire street width or an entire parking area. The pavement can also be installed in combination with impermeable pavements to infiltrate runoff and initiate a treatment train. Several applications use PICP in parking lot lanes or parking stalls to treat runoff from adjacent impermeable pavements and roofs. This design economizes PICP installation costs while providing sufficient treatment area for the runoff generated from impervious surfaces. Inlets can be places in the PICP to accommodate overflows from extreme storms. The stormwater volume to be captured, stored, infiltrated, or harvested determines the PICP scale required.

Specific design requirements relating to the structural stability of permeable pavements are beyond the scope of this manual. The reader is referred to the AASHTO Flexible Pavement Method for structural design requirements. The following guidelines are presented to ensure that permeable pavements are properly located, designed, and constructed to meet water quality objectives.

1. A washed aggregate base must be used, and washed 57-size stone is generally acceptable. Fine particles from standard “crusher run” will clog the pores at the bottom of the pavement and will not be allowed.

2. Low traffic volume – less than 100 axles per day. Areas with higher traffic volume may be able to use permeable pavement in parking stalls, and use regular pavement in drive aisles.

3. As shown in Figure 1 below, the seasonal high water table must be at least 2 ft below the base of the permeable pavement or gravel storage layer. Water tables approaching the permeable pavement system will not allow water to exfiltrate.

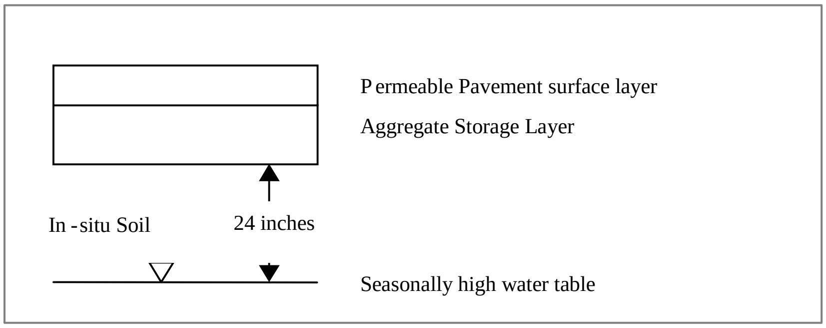



Figure 1 Schematic of Water Table Design Constraint

4. Permeable pavement should not be placed where upland land disturbance is occurring or will potentially occur. Land disturbance upland of the lot could result in frequent pavement clogging.

5. Avoid overhanging trees above the permeable pavement installation.

6. Steeper slopes can reduce the storage capacity of the permeable pavement, so it is important that the top of the soil subgrade (the bottom of the aggregate storage layer) be as close to flat as practicable (slope of ≤0.5%). If the top of the soil subgrade is >0.5%, baffles, partitions, berms, or terracing shall be installed to promote infiltration across the entire area of the subgrade and to reduce the potential for lateral flow. The surface of the permeable pavement shall be no more than 6%.

7. During preparation of the subgrade, special care must be made to avoid compaction of soils. Compaction of the soils can reduce the infiltration capacity of the soil.

8. Permeable pavement should not be designed to receive concentrated flow from roofs or other surfaces. Incidental run-on from stabilized areas is permissible, but the permeable pavement should be designed primarily to infiltrate the rain that falls on the pavement surface itself.

9. Permeable pavement systems are not allowed in areas, such as buffers, where impervious surfaces are not permitted.

10. The construction sequence will be inspected to ensure that the surface installation is planned to be completed after adjacent areas are stabilized with vegetation. Run-on to the permeable pavement from exposed areas can cause the system to perform ineffectively due to clogging.

### Specific Design Considerations and Limitations

The load-bearing and infiltration capacities of the subgrade soil, the infiltration capacity of the paver surface, and the storage capacity of the stone base/subbase are the key stormwater-design parameters. To compensate for the lower structural support capacity of clay soils, additional subbase depth is often required. The increased depth also provides additional storage volume to compensate for the lower infiltration rate of the clay subgrade. Underdrains elevated above the subgrade clay soil are often used in PICP, further making it suitable for many clay soils by infiltrating some of the water and filtering and draining the remainder. In addition, an impermeable liner may be installed between the subbase and the subgrade to limit water infiltration when clay soils have a high shrink-swell potential or there is a high depth to bedrock or water table (NCSU, 2008).

Measures should be taken to protect PICP from high sediment loads, particularly fine sediment. Appropriate pretreatment BMPs for run-on to pavers include filter strips and swales. Preventing sediment from entering the base or permeable pavement during construction is critical. Runoff from disturbed areas should be diverted away from the PICP until these areas are stabilized.

## Common Problems

PICP has the potential to become clogged with sediment if not protected from disturbed areas during construction activities.

Slope plays a role in applicability of PICP. Slopes greater than 2% may require additional design considerations, including terracing of soil subgrade.

PICP can cause safety concerns for disabled persons, bicycles, pedestrians wearing high-heels, and the elderly (SPU, 2009). Many PICP paver designs are ADA compliant, and other areas may require solid interlocking concrete pavements.

## Maintenance

The most prevalent maintenance concern is the potential clogging of the openings and joints between the pavers. Fine particles that can clog the openings are deposited on the surface from vehicles, the atmosphere, and runoff from adjacent land surfaces. Clogging will increase with age and use. However, while more particles become entrained in the pavement surface, it does not become impermeable. Studies of the long-term surface permeability of PICP and other permeable pavements have found high infiltration rates initially, a decrease, and then a leveling off with time. With initial infiltration rates of hundreds of inches per hour, the long-term infiltration capacity remains high even with clogging. When substantially clogged, surface infiltration rates usually well exceed 1 inch per hour, sufficient in most circumstances to effectively manage stormwater. Permeability can be increased with vacuum sweeping or, in extreme circumstances, by replacing the aggregate between pavers.

# Pervious Asphalt Pavement

## Practice Description

Pervious asphalt, also known as porous, permeable, “popcorn,” or open-graded asphalt, is standard hot-mix asphalt with reduced sand or fines that allow water to drain through it. Pervious asphalt over an aggregate storage bed will reduce stormwater runoff volume, rate, and pollutants. The reduced fines leave stable air pockets in the asphalt. The interconnected void space allows stormwater to flow through the asphalt and enter a crushed stone aggregate bedding layer and base that supports the asphalt while providing storage and runoff treatment. When properly constructed, pervious asphalt is a durable and cost-competitive alternative to conventional asphalt.

## Planning Considerations

Pervious asphalt can be used for municipal stormwater-management programs and private development applications. The runoff volume and rate control, plus pollutant reductions, allow municipalities to improve the quality of stormwater discharges. Municipal initiatives, such as Portland’s Green Streets program (shown in the photo above), use pervious asphalt to reduce combined sewer overflows by infiltrating and treating stormwater on site. Private development projects use pervious asphalt to meet post-construction stormwater quantity and quality requirements. The use of pervious asphalt can potentially reduce additional expenditures and land consumption for conventional collection, conveyance, and detention stormwater infrastructure.

Pervious asphalt can replace traditional impervious pavement for most pedestrian and vehicular applications. Open-graded asphalt has been used for decades as a friction course over impervious asphalt on highways to reduce noise, spray, and skidding. Highway applications with all-pervious asphalt surfacing have been used successfully for highway pilot projects in the United States; however, generally, pervious asphalt is recommended for low-volume and low-speed applications (Hossain et al., 1992). Pervious asphalt performs well in pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways. The environmental benefits from pervious asphalt allow it to be incorporated into municipal green infrastructure and low impact development programs. The appearance of pervious asphalt and conventional asphalt is very similar. The surface texture of pervious asphalt is slightly rougher, providing more traction to vehicles and pedestrians.

## Design Criteria

Pervious asphalt should be designed and sited to intercept, contain, filter, and infiltrate stormwater on site. Several design possibilities can achieve these objectives. For example, pervious asphalt can be installed across an entire street width or an entire parking area. The pavement can also be installed in combination with impermeable pavements or roofs to infiltrate runoff. Several applications use pervious asphalt in parking lot lanes or parking stalls to treat runoff from adjacent impermeable pavements and roofs. This design economizes pervious asphalt installation costs while providing sufficient treatment area for the runoff generated from impervious surfaces. Inlets can be placed in the pervious asphalt to accommodate overflows from extreme storms. The stormwater volume to be captured, stored, infiltrated, or harvested determines the scale of permeable pavement required.

Pervious asphalt comprises the surface layer of the permeable pavement structure and consists of open-graded coarse aggregate, bonded together by bituminous asphalt. Polymers can also be added to the mix to increase strength for heavy load applications. The thickness of pervious asphalt ranges from 2 to 4 inches depending on the expected traffic loads. For adequate permeability, the pervious asphalt should have a minimum of 16% air voids. Additional subsurface components of this treatment practice (illustrated in Figure 1) include the following (National Asphalt Pavement Association, 2008):

- *Choke course* - This permeable layer is typically 1-2 inches thick and provides a level and stabilized bed surface for the pervious asphalt. It consists of small-sized, open-graded aggregate.
- *Open-graded base reservoir* - This aggregate layer is immediately beneath the choke layer. The base is typically 3-4 inches thick and consists of crushed stones typically 3/4 to 3/16 inch. Besides storing water, this high-infiltration rate layer provides a transition between the bedding and subbase layers.
- *Open-graded subbase reservoir* - The stone sizes are larger than the base, typically ¾ to 2½ inch stone. Like the base layer, water is stored in the spaces among the stones. The subbase layer thickness depends on water storage requirements and traffic loads. A subbase layer may not be required in pedestrian or residential driveway applications. In such instances, the base layer is increased to provide water storage and support.
- *Underdrain (optional)* - In instances where pervious asphalt is installed over low-infiltration rate soils, an underdrain facilitates water removal from the base and subbase. The underdrain is perforated pipe that ties into an outlet structure. Supplemental storage can be achieved by using a system of pipes in the

aggregate layers. The pipes are typically perforated and provide additional storage volume beyond the stone base.

- *Geotextile (optional)* - This can be used to separate the subbase from the subgrade and to prevent the migration of soil into the aggregate subbase or base.
- *Subgrade* - The layer of soil immediately beneath the aggregate base or subbase. The infiltration capacity of the subgrade determines how much water can exfiltrate from the aggregate into the surrounding soils. The subgrade soil is generally not compacted.

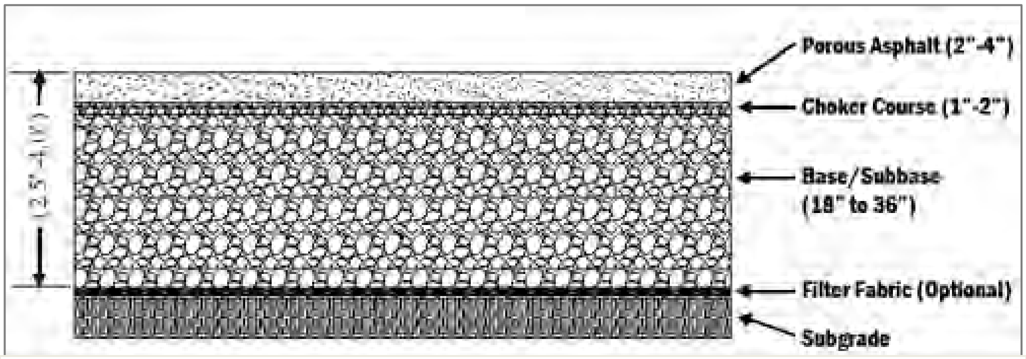



Figure 1 Typical Porous Asphalt Pavement Section (diagram adapted from USEPA, 1986)

The same equipment can be used for mixing and laying permeable asphalt as for conventional asphalt. The method for laying the asphalt will also be similar. During compaction of the asphalt, minimal pressure should be used to avoid closing pore space. Vehicular traffic should be avoided for 24 to 48 hours after pavement is installed.

The load-bearing and infiltration capacities of the subgrade soil, the infiltration capacity of the pervious asphalt, and the storage capacity of the stone base/subbase are the key stormwater-design parameters. To compensate for the lower structural support capacity of clay soils, additional subbase depth is often required. The increased depth also provides additional storage volume to compensate for the lower infiltration rate of the clay subgrade. Underdrains are often used when permeable pavements are installed over clay. In addition, an impermeable liner may be installed between the subbase and the subgrade to limit water infiltration when clay soils have a high shrink-swell potential, or if there is a high depth to bedrock or water table (Hunt and Collins, 2008).

## Common Problems

Measures should be taken to protect permeable pavement from high sediment loads, particularly fine sediment. Appropriate pretreatment BMPs for run-on to permeable pavement include filter strips and swales. Preventing sediment from entering the base of permeable pavement during construction is critical. Runoff from disturbed areas should be diverted away from the permeable pavement until these areas are stabilized.

Several factors may limit permeable pavement use. Pervious asphalt has reduced strength compared to conventional asphalt and will not be appropriate for applications with high volumes and extreme loads. It is not appropriate for stormwater hotspots where hazardous materials are loaded, unloaded, stored, or where there is a potential for spills and fuel leakage. For slopes greater than 2 percent, terracing of the soil subgrade base may likely be needed to slow runoff from flowing through the pavement structure.

## Maintenance

The most prevalent maintenance concern is the potential clogging of the pervious asphalt pores. Fine particles that can clog the pores are deposited on the surface from vehicles, the atmosphere, and runoff from adjacent land surfaces. Clogging will increase with age and use. While more particles become entrained in the pavement surface, it does not become impermeable. Studies of the long-term surface permeability of pervious asphalt and other permeable pavements have found high infiltration rates initially, followed by a decrease, and then leveling off with time (Bean et al., 2007). With initial infiltration rates of hundreds of inches per hour, the long-term infiltration capacity remains high even with clogging. When clogged, surface infiltration rates usually well exceed 1 inch per hour, which is sufficient in most circumstances for the surface to effectively manage intense stormwater events (Interlocking Concrete Pavement Institute, 2000). Permeability can be increased with vacuum sweeping. In areas where extreme clogging has occurred, half-inch holes can be drilled through the pavement surface every few feet or so to allow stormwater to drain to the aggregate base. A stone apron around the pavement connected hydraulically to the aggregate base and subbase can be used as a backup to surface clogging or pavement sealing.

Due to the well-draining stone bed and deep structural support of pervious asphalt pavements, they tend to develop fewer cracks and potholes than conventional asphalt pavement. When cracking and potholes do occur, a conventional patching mix can be used. Freeze/thaw cycling is a major cause of pavement breakdown; pervious asphalt parking lots can have a lifespan of more than 30 years because of the reduced freeze/thaw stress (Gunderson, 2008).

Cold weather and frost penetration do not negatively impact surface infiltration rates. Pervious asphalt freezes as a pervious medium rather than a solid block because permeable pavement systems are designed to be well drained; infiltration capacity is preserved because of the open void spaces (Gunderson, 2008). However, plowed snow piles should not be left to melt over the pervious asphalt, as they can receive high sediment concentrations that can clog the pavement system more quickly.

Permeable pavements do not treat chlorides from road salts but also require less applied deicer. Deicing treatments are a significant expense, and chlorides in stormwater runoff have substantial environmental impacts. Reducing chloride concentrations in runoff is achieved only through reduced application of road salts, because removal of chloride with stormwater BMPs is not effective.

# Pervious Concrete

Photo Courtesy of pavementinteractive.org

## Practice Description

Pervious concrete, also known as pervious, gap-graded, or enhanced porosity concrete, is concrete with reduced sand or fines and allows water to drain through it. Pervious concrete is often constructed over an aggregate storage bed to allow for stormwater infiltration and temporary storage. This aggregate layer not only provides temporary stormwater storage but also helps to support the concrete. Pervious concrete has less sand and fines than standard concrete, which leaves stable air pockets in the concrete that allow water to flow through. This void space is generally between 15 and 35 percent. When properly installed, pervious concrete is a durable and low-maintenance paving option.

## Planning Considerations

Pervious concrete can be used for municipal stormwater management programs and private development applications. The runoff volume and rate control, plus pollutant reductions, allow municipalities to improve the quality of stormwater discharges. Municipal initiatives, such as Chicago’s Green Alley program, use pervious concrete to reduce combined sewer overflows and to minimize localized flooding by infiltrating and treating stormwater on site. Private development projects use pervious concrete to meet post-construction stormwater quantity and quality requirements. The use of pervious concrete can potentially reduce additional expenditures and land consumption for conventional collection, conveyance, and detention stormwater infrastructure. Public and private developments have used pervious concrete, which is a naturally brighter surface than traditional asphalt, to reduce lighting needs and increase nighttime safety.

Pervious concrete can replace traditional impervious pavement for most pedestrian and vehicular applications except high-volume/high-speed roadways. Pervious concrete can be designed to handle heavy loads, but surface abrasion from constant traffic will cause the pavement to deteriorate more quickly than conventional concrete. Pervious concrete has performed successfully in pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways. The environmental benefits from pervious concrete allow it to be incorporated into municipal green infrastructure and low impact development programs. In addition to providing stormwater volume and quality management, the light color of concrete is cooler than conventional asphalt and helps to reduce urban temperatures and improve air quality (Grant et al., 2003; Vingarzan and Taylor, 2003). Unlike the smoothed surface of conventional concrete, the surface texture of pervious concrete is slightly rougher, providing more traction to vehicles and pedestrians.

## Design Criteria

Pervious concrete should be designed and sited to intercept, contain, filter, and infiltrate stormwater on site. Several design possibilities can achieve these objectives. For example, pervious concrete can be installed across an entire street width or an entire parking area. The pavement can also be installed in combination with impermeable pavements or roofs to infiltrate runoff. Several applications use pervious concrete in parking lot lanes or parking stalls to treat runoff from adjacent impermeable pavements and roofs. This design economizes pervious concrete installation costs while providing sufficient treatment area for the runoff generated from impervious surfaces. Inlets can be placed in the pervious concrete to accommodate overflows from extreme storms. The stormwater volume to be captured, stored, infiltrated, or harvested determines the scale of permeable pavement required.

Pervious concrete comprises the surface layer of the permeable pavement structure and consists of portland cement, open-graded coarse aggregate (typically 5/8 to 3/8 inch), and water. Admixtures can be added to the concrete mixture to enhance strength, increase setting time, or add other properties. The thickness of pervious concrete ranges from 4 to 8 inches depending on the expected traffic loads. Additional subsurface components of this treatment practice are illustrated in Figure 1 and include the following (National Ready Mix Concrete Association (NRMCA), 2008):

- *Choke course* - This permeable layer is typically 1-2 inches thick and provides a level bed for the pervious concrete. It consists of small-sized, open-graded aggregate.
- *Open-graded base reservoir* - This aggregate layer is immediately beneath the choke layer. The base is typically 3-4 inches thick and consists of crushed stones typically 3/4 to 3/16 inch. Besides storing water, this high-infiltration rate layer provides a transition between the bedding and subbase layers.
- *Open-graded subbase reservoir* - The stone sizes are larger than the base, typically 2½ to 2¾ inch stone. Like the base layer, water is stored in the spaces among the stones. The subbase layer thickness depends on water storage

requirements and traffic loads. A subbase layer may not be required in pedestrian or residential driveway applications. In such instances, the base layer is increased to provide water storage and support.

- *Underdrain (optional)* - In instances where pervious concrete is installed over low-infiltration rate soils, an underdrain facilitates water removal from the base and subbase. The underdrain is perforated pipe that ties into an outlet structure. Supplemental storage can be achieved by using a system of pipes in the aggregate layers. The pipes are typically perforated and provide additional storage volume beyond the stone base.
- *Geotextile (optional)* - This can be used to separate the subbase from the subgrade and to prevent the migration of soil into the aggregate subbase or base.
- *Subgrade* - The layer of soil immediately beneath the aggregate base or subbase. The infiltration capacity of the subgrade determines how much water can exfiltrate from the aggregate into the surrounding soils. The subgrade soil is generally not compacted.

Properly installed pervious concrete requires trained and experienced producers and construction contractors. The installation of pervious concrete differs from conventional concrete in several ways. The pervious concrete mix has low water content and will therefore harden rapidly. Pervious concrete needs to be poured within one (1) hour of mixing. The pour time can be extended with the use of admixtures. A manual or mechanical screed set ½ inch above the finished height can be used to level the concrete.

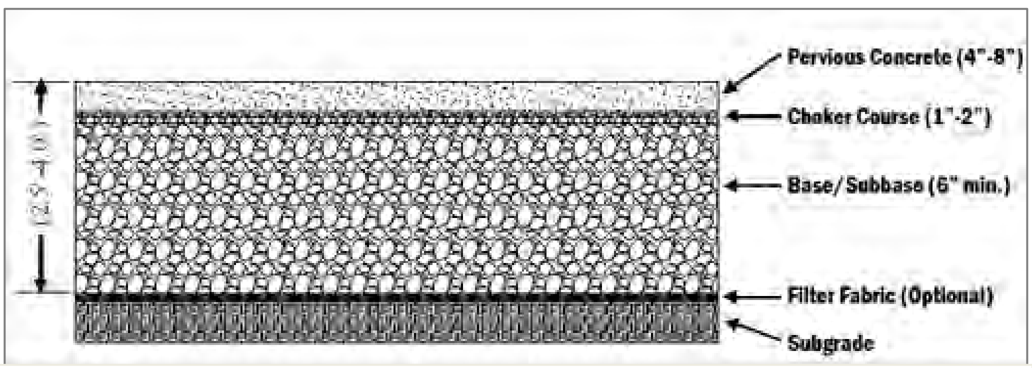



Figure 1 Typical Porous Asphalt Pavement Section (diagram adapted from USEPA, 1986)

Floating and troweling are not used, as these actions may close the surface pores. Consolidation of the concrete, typically with a steel roller, is recommended within 15 minutes of placement. Pervious concrete also requires a longer time to cure. The concrete should be covered with plastic within 20 minutes of setting and allowed to cure for a minimum of 7 days (NRMCA, 2008).

## Siting Considerations

- Do not install in areas where hazardous materials are loaded, unloaded, or stored.
- Avoid high sediment-loading areas.
- Divert runoff from disturbed areas until stabilized.
- Do not use sand for snow or ice treatment.
- Periodic maintenance to remove fine sediments from paver surface will optimize permeability.

## Common Problems

The load-bearing and infiltration capacities of the subgrade soil, the infiltration capacity of the pervious concrete, and the storage capacity of the stone base/subbase are the key stormwater design parameters. To compensate for the lower structural support capacity of clay soils, additional subbase depth is often required. The increased depth also provides additional storage volume to compensate for the lower infiltration rate of the clay subgrade. Underdrains are often used when permeable pavements are installed over clay. In addition, an impermeable liner may be installed between the subbase and the subgrade to limit water infiltration when clay soils have a high shrink-swell potential, or if there is a high depth to bedrock or water table (Hunt and Collins, 2008).

Measures should be taken to protect permeable pavement from high sediment loads, particularly fine sediment. Appropriate pretreatment BMPs for run-on to permeable pavement include filter strips and swales. Preventing sediment from entering the base of permeable pavement during construction is critical. Runoff from disturbed areas should be diverted away from the permeable pavement until the areas are stabilized.

Several factors may limit permeable pavement use. Pervious concrete has reduced strength compared to conventional concrete and will not be appropriate for applications with high volumes and extreme loads. It is not appropriate for stormwater hotspots where hazardous materials are loaded, unloaded, stored, or where there is a potential for spills and fuel leakage. For slopes greater than 2 percent, terracing of the soil subgrade base may likely be needed to slow runoff from flowing through the pavement structure. In another approach for using pervious concrete slopes, lined trenches with underdrains can be dug across slope to intercept flow through the subbase (ACPA, 2006).

## Maintenance

The most prevalent maintenance concern is the potential clogging of the pervious concrete pores. Fine particles that can clog the pores are deposited on the surface from vehicles, the atmosphere, and runoff from adjacent land surfaces. Clogging will increase with age and use. While more particles become entrained in the pavement surface, it does not become impermeable. Studies of the long-term surface permeability of pervious concrete and other permeable pavements have found high infiltration rates initially, followed by a decrease, and then leveling off with time (Bean et al., 2007a). With initial infiltration rates of hundreds of inches per hour, the long-term infiltration capacity remains high even with clogging. Permeability can be increased with vacuum sweeping. In areas where extreme clogging has occurred, half-inch holes can be drilled through the pavement surface every few feet or so to allow stormwater to drain to the aggregate base. Many large cuts and patches in the pavement will weaken the concrete structure.

Cold weather and frost penetration do not negatively impact surface infiltration rates. Permeable concrete freezes as a pervious medium rather than a solid block because permeable pavement systems are designed to be well drained; infiltration capacity is preserved because of the open void spaces (Gunderson, 2008).

# Bioretention (Rain Gardens)

## Practice Description

A bioretention cell consists of a depression in the ground filled with a soil media mixture that supports various types of water-tolerant vegetation. The surface of the BMP is depressed in bioretention facilities to allow for ponding of runoff that filters through the BMP media. Water exits the bioretention area via exfiltration into the surrounding soil, flow out an underdrain, and evapotranspiration. The surface of the cell is protected from weeds, mechanical erosion, and desiccation by a layer of mulch. Bioretention is an efficient method for removing a wide variety of pollutants, such as suspended solids, heavy metals, nutrients, and pathogens (North Carolina Cooperative Extension (NCCE), 2007). Bioretention areas provide some nutrient uptake in addition to physical filtration. If located at a site with appropriate soil conditions to provide infiltration, bioretention can also be effective in reducing peak runoff rates, reducing runoff volumes, and recharging groundwater.

## Planning Considerations

Many development projects present a challenge to the designer of conventional stormwater BMPs because of physical site constraints. Bioretention areas are intended to address the spatial constraints that can be found in densely developed urban areas where the drainage areas are highly impervious. They can be used on small urban sites that would not normally support the hydrology of a wet detention pond and where the soils would not allow for an infiltration device. Median strips, ramp loops, traffic circles, and parking lot islands are good examples of typical locations for bioretention areas.

Bioretention units are ideal for distributing several units throughout a site to provide treatment of larger areas. Developments that incorporate this decentralized approach to stormwater management can achieve savings by eliminating stormwater-management ponds; reducing pipes, inlet structures, curbs and gutters; and having less grading and clearing. Depending on the type of development and site constraints, the costs for using decentralized bioretention stormwater-management methods can be reduced by 10 to 25 percent compared to stormwater and site development using other BMPs (Coffman, 1993).

Figure 1 Bioretention in Parking Lot Island

Bioretention facilities are generally most effective if they receive runoff as close as possible to the source. Reasons for this include: minimizing the concentration of flow to reduce entry velocity; reducing the need for inlets, pipes, and downstream controls; and allowing for blending of the facilities with the site (e.g., parking median facilities). For sites where infiltration is being utilized, it also avoids excessive groundwater mounding. Where bioretention takes the place of required green space, the landscaping expenses that would be required in the absence of bioretention should be subtracted when determining the actual cost (LID Center, 2003). Bioretention cells may also address landscaping/green space requirements of some local governments (Wossink and Hunt 2003).

## Design Criteria

Design is an eight-step process:

1. Understand basic layout concepts.
2. Determine the volume of water to treat.
3. Determine the surface area required.
4. Select the soil media type.
5. Decide the depth of soil media.
6. Size the underdrain pipes (if necessary).
7. Select the appropriate overflow or bypass method.
8. Select plants and mulch.

## Step 1: Understand Basic Layout Concepts

The layout of bioretention areas varies according to individual sites and to specific site constraints such as underlying soils, existing vegetation, drainage, location of utilities, sight distances for traffic, aesthetics, and ease of maintenance. Figure 2 illustrates a concept for a bioretention traffic island. These types of bioretention facilities typically take up no more space than what is required by typical zoning rules, and they provide stormwater treatment as well as site aesthetics. The following photographs are examples of existing bioretention cells that have been designed using these techniques. These cells blend into the landscape and appear to be typical flowerbeds or medians. Often, bioretention cells can be designed with flowering plants to enhance the landscape.

### *Examples of Previously Installed Bioretention Cells*

Figure 2 shows an 8-inch gravel strip followed by 5 feet of grass for pretreatment along the side that receives water from the jogging trail. This is an example of both gravel strip pretreatment design as well as when to maintain the gravel strip. This strip has become overgrown with grass and has been clogged with sediment. The mulch has also become thin, and should be replaced.

Figure 2 Bioretention Cell with Pretreatment: Gravel and Grass (Needs Maintenance)

Figure 3 shows a bioretention cell with a pretreatment forebay. Notice the sediment that has settled onto the rocks. Without the forebay, this sediment would have collected on the top of the bioretention cell, clogged the soil media, and would have become a maintenance burden. Forebays that are located inside a cell should be lined in order to ensure that the treatment volume drains through the media.

Figure 3 Bioretention Cell with Pretreatment Forebay

### *Examples of Additional Design Options*

#### Use of Flow Splitters

Bioretention units can be designed using a flow splitter so that only the treatment volume is directed into the cell. An example of this design is provided as Figure 4. This example shows a filter strip, though it is not required for every design.

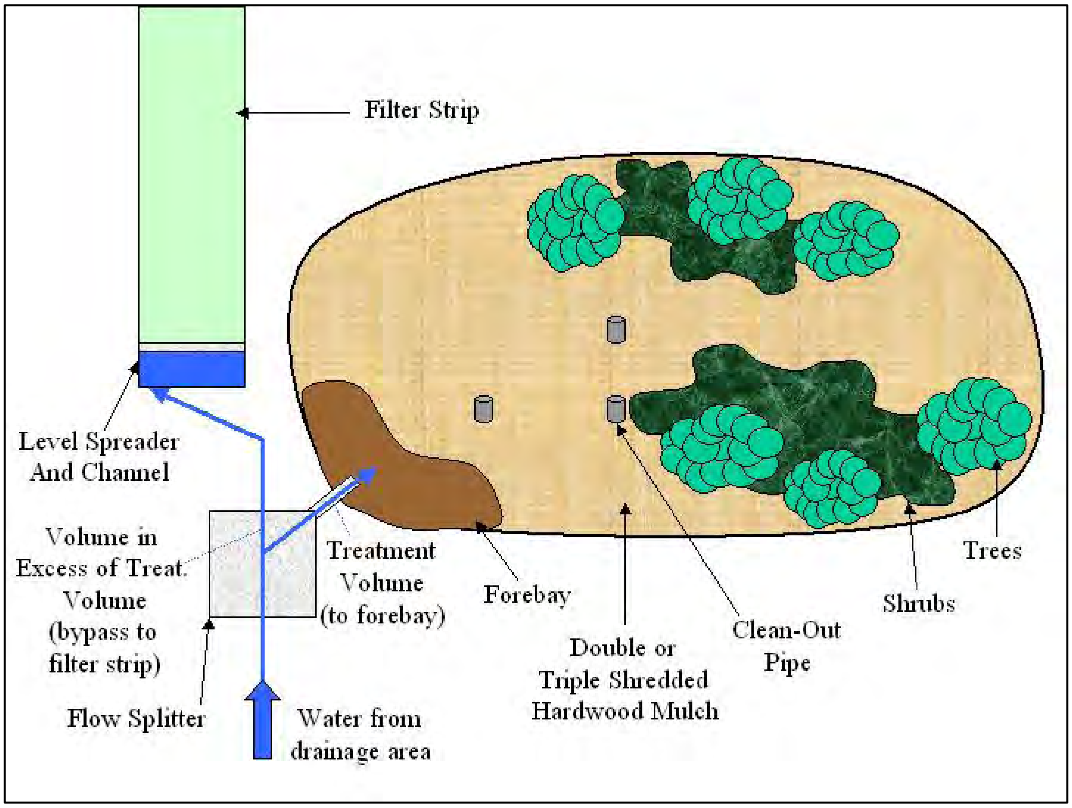



Figure 4 Typical Bioretention Cell Using a Flow Splitting Device (Source: North Carolina Department of Environment and Natural Resources (NCDENR)

### Use of Overflow Devices

Bioretention units can be designed using an overflow device so that water in excess of the treatment volume overflows to a filter strip. An example of this design is provided in Figure 5. This example shows a filter strip, though it is not required for every design.

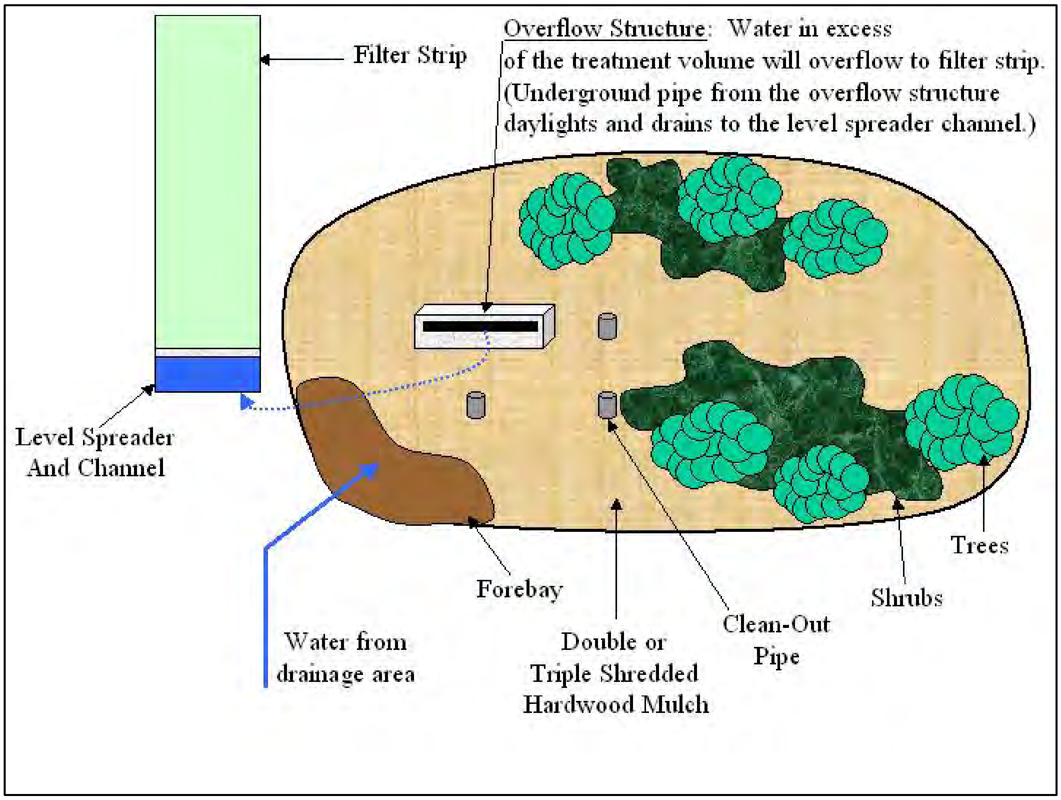



Figure 5 Typical Bioretention Cell Using an Overflow Device (Source: NCDENR)

### Internal Water Storage Zones (IWS)

An internal water storage zone (IWS) can be created by the addition of an elbow in the underdrain piping at a 90-deg angle vertically perpendicular to the horizontal underdrain, either in retrofit conditions or in new installations. This upturned elbow on underdrains can force water to remain longer in the bottom of the cell, creating a saturated IWS. If this zone remains saturated long enough, anaerobic conditions are created, promoting denitrification and increased nitrogen removal (Passeport et al., 2009).

There are several benefits to using the upturned elbow and IWS. The IWS works for both pollutant and peak flow reduction as anaerobic conditions can be created to increase nitrogen removal. It also allows more water to infiltrate into the surrounding soils. If an upturned elbow is installed correctly in sufficiently permeable soils, it may only rarely generate outflows.

The use of upturned elbows and IWS can be especially beneficial in areas where surrounding sandy soils can be ideal for infiltration, reducing outflows and surface water runoff. Additionally, there is often a cost benefit for using upturned elbows, both for new installations and retrofits. In new installations, a cost-savings is associated with installation since the invert of the outlet is not as deep. Often with IWS, there can be less trenching and fewer materials associated with using it. In retrofits, upturned elbows can be cheaply added to existing bioretention cells where increased nitrogen and phosphorus removal rates are needed. Additionally, cells with IWS can be added as retrofits even in areas with restricted outlet depth.

For an internal water storage zone to work correctly, the underlying soils must have some permeability. In general, if the underlying soils are Group A or B soils with a low clay content, the IWS will be effective. If soils are too compacted, water will not infiltrate and may stagnate in the lower portion, causing problems for the BMP. Media depth above the bottom gravel and underdrain layer must be at least 3 feet. The top of IWS should be separated from the outlet and bowl surface by at least 12 inches (ideally 18 inches). See Figure 6.

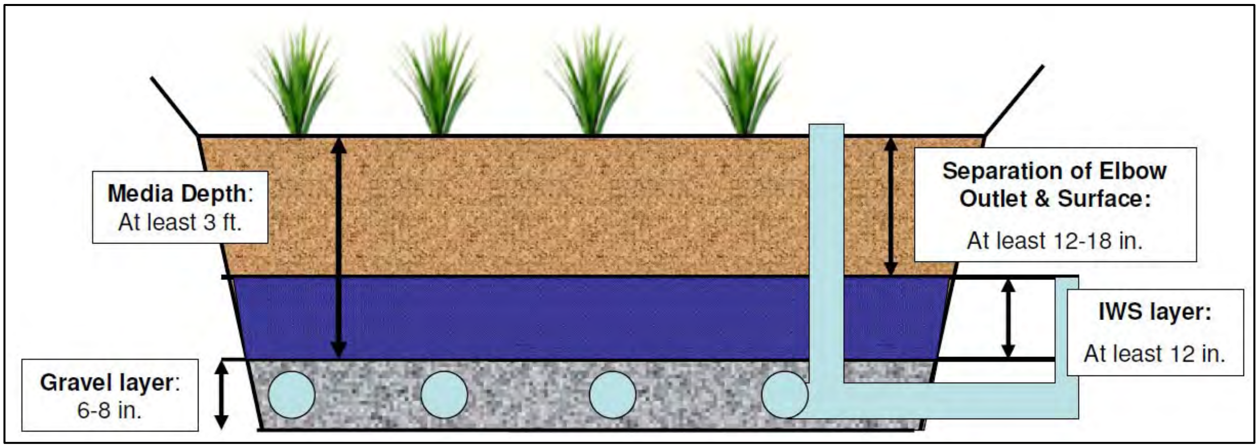



Figure 6  Bioretention Cell showing IWS Zones (Source: NCDENR)

### Parking Lot Diversion Method

A bioretention area that can be installed along the perimeter of a parking lot is shown in Figure 7. The water is diverted to the bioretention area through the use of a curb diversion structure. A 2-foot buffer between the curb and the bioretention area serves as pretreatment and reduces the possibility of drainage seeping under the pavement section and creating “frost heave” during winter months. Flow diversion by curb diversion structures may not meet the volume attainment requirements.

A berm one foot in height separates the swale from the bioretention area. The bioretention area should be at an elevation such that, when the design ponding depth is reached, additional flow continues down the swale and is diverted from the bioretention cell.

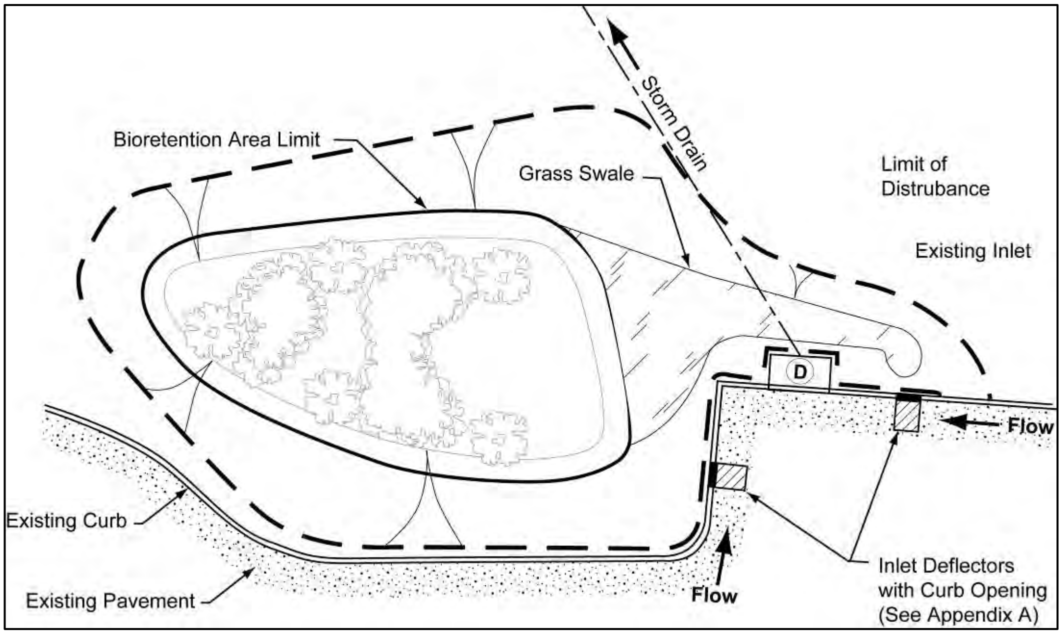



Figure 7 Parking Edge and Perimeter with Curb (Source: Prince George's County, 2000)

### Bioretention Cells on Steep Slopes

Figure 8 depicts a bioretention terrace that can be used in sloping terrain (for 10-20% slopes). An impermeable or very low-permeability geomembrane must be used against the gabions or similar retaining structure to prevent flow from leaving the treatment unit through that surface. An underdrain could be placed at the low point of the filter if the native soil against which the unit is built will not provide adequate infiltration capacity.

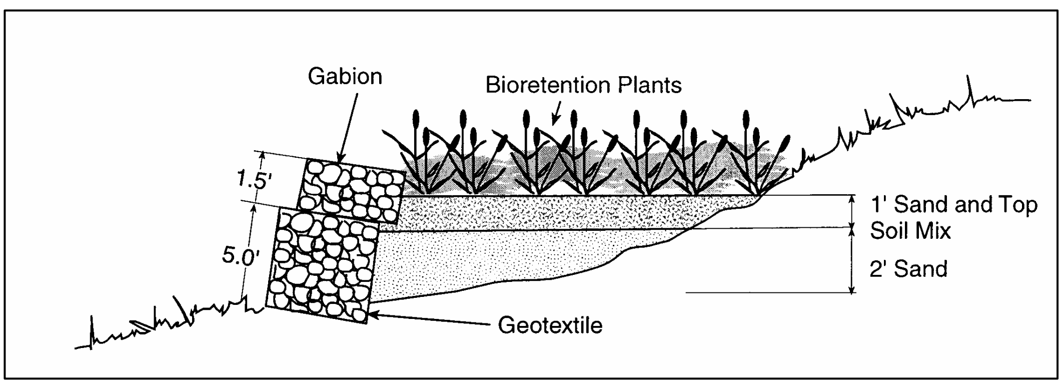



Figure 8 Bioretention Terrace Suitable for Use on Slopes 10-20%

### Pretreatment Options

Inflow must enter a bioretention cell via sheet flow (1ft/sec for cells with mulch, or 3.0 ft/sec for grassed cells) or alternative energy-dissipating devices must be used. Sheet flow provides for the most even distribution of flow and the least energy (minimizing erosion). Sheet flow can be naturally provided, as in the case of a gently sloping parking lot with no curb and gutter or a vegetated buffer/filter strip, or it can be designed into the device by the use of a level spreader. In some instances sheet flow is not attainable and the inflow will enter from concentrated sources such as curb diversion structures, drainage pipes, grassy swales, etc. In these cases, a riprap-lined entrance, a forebay, or other energy-dissipating device must be used.

The water treatment volume shall be calculated as specified in Appendix A. The cell must be designed to have a pretreatment area. The most commonly used pretreatment devices are these:

1) A grass and gravel combination: This should consist of 8 inches of gravel followed by 3 to 5 feet of sod. See the *Sodding Practice* in Volume 1 for more information on sod installation.

2) A grassed water quality swale: A water quality swale shall be designed as specified in the *Grass Swale Practice*.

3) A forebay: The forebay should be 18-30 inches deep, and used only in areas where standing water is not considered a safety concern. The forebay should be deepest where water enters, and more shallow where water exits in order to dissipate hydraulic energy of the water flowing to the forebay. If there is a risk that water in the forebay could flow into the underdrain without first flowing to the cell, the forebay should also be lined.

### Maintenance Considerations

When performing the following remaining steps of designing a bioretention cell, consider how landscape professionals will later access the site for maintenance. Because the soil must be able to accommodate fast water infiltration, it cannot be compacted by heavy equipment. Is the forebay accessible for heavy equipment to remove sediment from it without driving onto the cell? Are the clean-out pipes accessible? All aspects of design should consider future maintenance.

### Construction Sequencing

The drainage area to the cell should be stabilized before cell construction begins in order to prevent clogging. For roadways draining to the cell, the subbase course (crusher run) and the base course layer of asphalt need to be in place prior to cell construction. If fines get washed into the excavated cell, they must be removed before building the cell, in order to restore the permeability of the in situ soils. It is recommended that the cell media be covered with impermeable plastic during construction.

## Step 2: Determine the Volume of Water to Treat

### *Water Volume*

An individual bioretention cell is intended to treat the first flush. *Appendix A: Erosion and Stormwater Runoff Calculations* details the volumetric calculation.

### *Siting Issues*

Bioretention facilities shall not be used in areas with the following characteristics:

- The seasonal high water table is less than 2 feet below the bottom of the cell.

- Slopes are 20 percent or greater, unless bioretention terraces are planned.
- Further construction is planned on either the immediately surrounding site or in outparcels that may drain to the bioretention site. (The upstream contributing drainage area must be completely and permanently stabilized, e.g., gravel base course driving surface (preferably paved), or a dense and vigorous vegetative cover. The heavy sediment load from a bare-earth construction site will cause premature failure of a bioretention BMP.)
- The cell is inaccessible for maintenance.
- The cell will not comply with local landscape ordinances.

### *Contributing Drainage Basin*

Consider the effect of large storms on potential erosion within the cell as well as potential overflow and downhill erosion upon water leaving the cell. The contributing area to an individual bioretention cell will typically be 5 acres or less, because many large watersheds will not have an area that is large enough to serve the treatment volume while also being high enough above the water table.

## Step 3: Determine the Surface Area and Depth Required

The cell can be designed to hold the first inch of rainfall from the entire drainage area. The required surface area of the bioretention cell is equal to the required treatment volume (as calculated using the Simple Method outlined in *Appendix A*) divided by the ponding depth. No dimension (width, length, or radius) can be less than 10 feet. This is to provide sufficient space for plants.

## Step 4: Select the Soil Media Type

The soil mix should be uniform and free of stones, stumps, roots, or other similar material greater than 2 inches. It should be a homogenous soil mix of 85-88 percent by volume sand (USDA Soil Textural Classification), 8 to 12 percent fines (silt and clay), and 3 to 5 percent organic matter (such as peat moss). The higher (12 percent) fines content should be reserved for areas where total nitrogen is the target pollutant. In areas where phosphorus is the target pollutant, lower (8 percent) fines should be used. Additionally, the phosphorus (P) content of the soil mix should be low. The P-Index for bioretention soil media should always range between 10 and 30, regardless of the target pollutant (Hunt and Lord, 2006). The P-Index is an extremely important design element. Cells that are constructed of high P-Index soils can export phosphorus.

The media should be tested to determine an actual drainage rate after placement. The permeability should fall between 1 and 6 inches per hour, and 1-2 inches per hour is preferred. As a rule of thumb, using the above-specified media, the infiltration rates should be approximately 2 in./hr and 1 in./hr for 8% and 12% fines, respectively, depending on the target pollutant. An estimated drainage rate for percent fines between 8 and 12 can be approximated during design by linear interpolation. If total suspended solids (TSS) or pathogens are the target pollutant, the higher permeability can be used because these two pollutants are removed on the surface of the bioretention cell rather than within the cell.

### Step 5: Determine the Soil Media Depth

Different pollutants are removed in various zones of the bioretention cell using several mechanisms. The TSS are removed both in pretreatment and on the surface of the cell itself. For that reason, TSS removal is not a major factor in depth of the cell design. Depth is, however, an issue for other pollutants. Metals are removed in the top layer of mulch and the soil, as they are often bound to sediment. Additionally, two thirds of phosphorus entering the cell is attached to soil particles. As a result, this portion is removed on the surface. The remaining third is soluble and is removed 12 inches or more below the surface. Bacterial, viral, and protozoan pathogens can be killed on the surface and removed throughout the cell by several mechanisms: sun-exposure, drying, sedimentation, and filtration (Hathaway and Hunt, 2008). Temperature is reduced at approximately 48 inches below the surface. Nitrogen is removed 30 inches below the surface. Initial research at North Carolina State University shows that using an upturned underdrain pipe may increase nitrogen removal. The upturned piped creates an anaerobic zone that may facilitate nitrogen removal. (See the *Internal Water Storage Zones* section of this practice for more information.) Consider the types of pollutants to be removed, and select an appropriate media depth.

The ponding depth above the media and mulch shall be 12 inches or less (9 inches or less is preferred). This is based on both the typical inundation tolerance of the vegetation used in bioretention facilities as well as the ability of the ponded water to drain into the soil within the required time.

The depth of the media in a bioretention cell should be between 2 and 4 feet. This range reflects the fact that most of the pollutant removal occurs within the first 2 feet of soil, and excavations deeper than 4 feet become more expensive. The depth should accommodate the vegetation (shrubs or trees). If the minimum depth of 2 feet is used, only shallow-rooted plants can be planted. Grassed bioretention cells with no IWS can be as shallow as 2 feet. However, if nitrogen is the target pollutant, the cell should have at least 30 inches of media because, as previously discussed, nitrogen is removed 30 inches below the surface. Bioretention facilities where shrubs or trees are planted can be as shallow as 3 feet. If large trees are to be planted in deep fill media, care should be taken to ensure that they would be stable and not fall over. As stated above, if IWS is used, cells must have a minimum depth of 3 feet.

If underdrain piping is used (which is only for cases in which the infiltration rate is less than 2 in./hr), the media is as shown in Figure 9. This figure shows a cross-sectional design. No. 57 stone shall be installed around the underdrain. Crusher run shall not be used around the underdrain, as it can form an impermeable layer (Amerson et al., 1991). For pretreatment, the gravel and grass option is presented in this figure because it is one of the most common pretreatment options. The design shown here is for a bioretention cell in a non-developing area. Bioretention cells should be used only in non-developing areas. If there is any concern that the surrounding area may be developed in the future, consider using an alternate BMP or protecting the BMP from sediment. If this is only a nominal concern, use 2 inches of either No. 8 or No. 89 washed choking stone in place of the filter fabric shown in Figure 9.

If an underdrain system is not used, the cross-sectional design of the cell will be the same although the underdrain will be omitted. Figure 9 is shown using the gravel and grass pretreatment option, though it could be modified to use any of the pretreatment methods.

This figure also shows an overflow structure. Typically, an overflow structure is adapted from an existing drainage culvert inlet.

In Figure 9, the vertical sides of the bioretention cell do not have to be at a specified angle. However, the surface area of the bottom of the cell should be maximized.

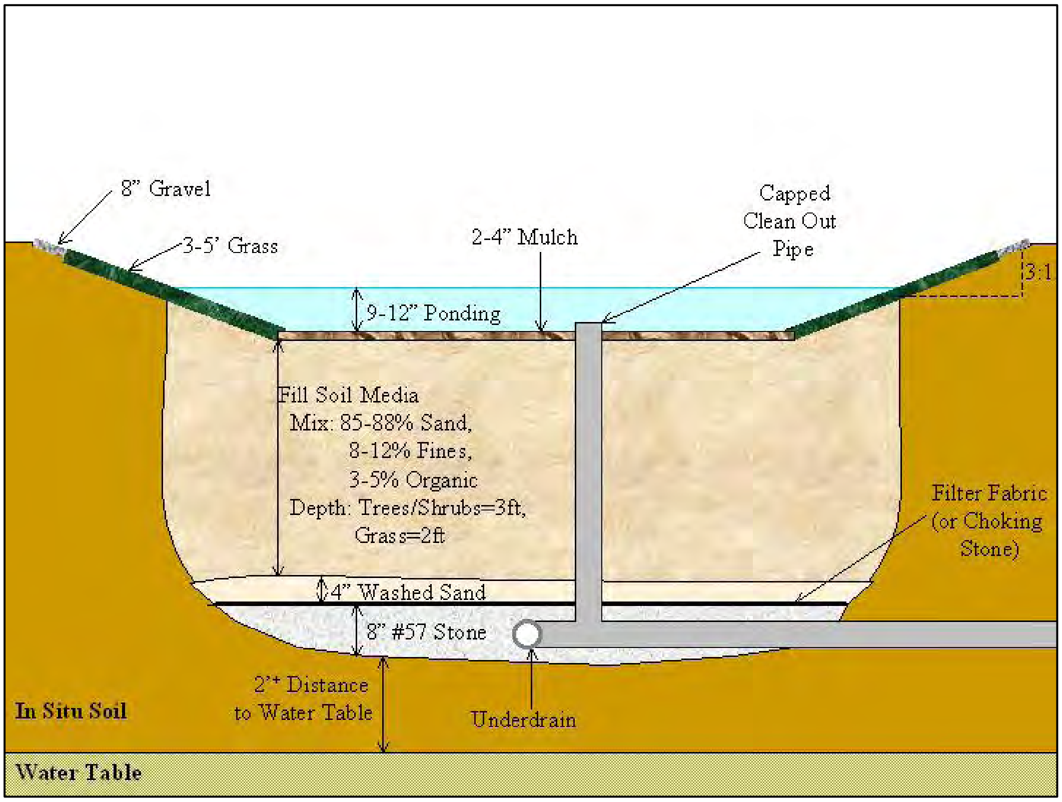



Figure 9: Bioretention Conceptual Layout: Cross-Section (Source: NCDENR)

### *Sediment Accumulation*

There should be very little, if any, sediment accumulation in a bioretention cell, since the upstream drainage basin must be stabilized prior to bringing the bioretention cell into service, and since pretreatment is required prior to the BMP.

### *Drainage Considerations*

Water shall pond above the cell for a maximum of 12 hours. Water must then drain to a level 24 inches below the surface of the cell within 48 hours (maximum) to allow the appropriate contact time for pollutant removal. This requirement is demonstrated in Figure 10. The time to drain the ponded volume is simply the depth of the ponding in inches, divided by the limiting drainage rate. If the cell has an underdrain, the length of time that it takes to drain the ponding volume of a bioretention cell is controlled by the infiltration rate of the media. If the cell does not have an underdrain and is an infiltration type system, it will be controlled by the lesser of the infiltration rate of the media or the infiltration rate of the native soil.

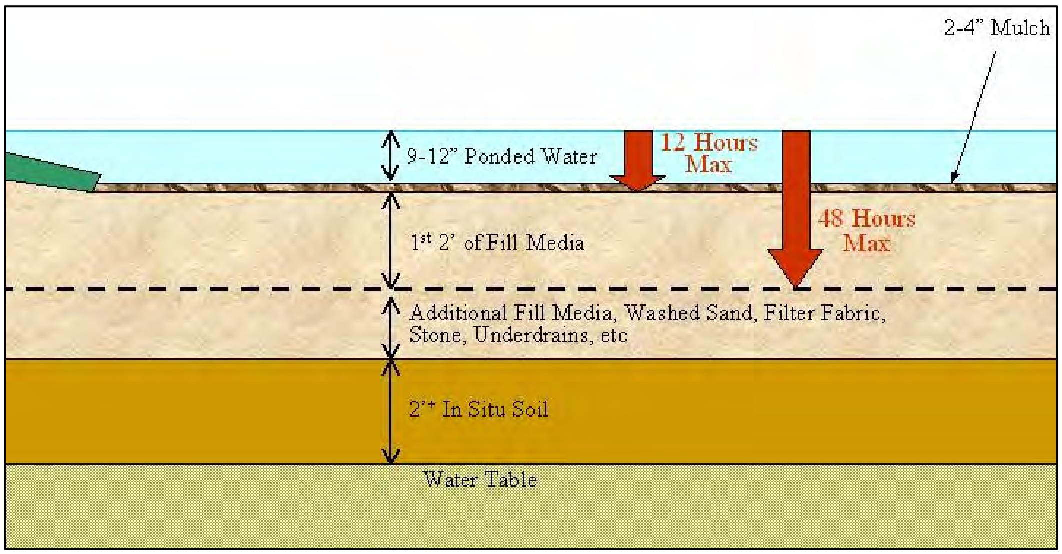



Figure 10: Bioretention Drain Time (Source: NCDENR)

## Step 6: Size the Underdrains (if required)

The need for an underdrain is driven by the permeability of the in situ soil. If the in situ soil has a high permeability, the system can be designed as an infiltration type bioretention facility with no underdrains. If in situ soil permeability is less than 2 inches/hour, the bioretention facility will likely have an underdrain system. If the in situ soil drains more slowly than the planting media, the designer should include an explanation of how water will drain from the media. The underdrain system will connect to another BMP or to the conveyance system. Due to the risk of underdrain clogging, designers are encouraged to install more than one underdrain of smaller diameter in order to facilitate drainage. The minimum diameter of pipe for underdrain systems is four inches. As previously discussed, an upturned elbow may be used.

Clean-out pipes must be provided (minimum one per every 1,000 square feet of surface area). Clean-out pipes must be capped.

## Step 7: Select the Appropriate Overflow Structure

The overflow structure should be sized to accommodate storm volumes in excess of the first flush. The first available outlet on the outlet structure should therefore be placed at the height of the first flush, which is the ponded level of the bioretention cell. Use the weir equation to consider the height of the water above the weir during overflow from large storm events. Typically, water can rise about 2 inches above the ponded water level. But, this height can be higher, about 4″-6″ above the ponded water level, if required by design restraints. A particular design storm is not specified for overflow structure design. Professional judgment should be used when considering potential flooding risks outside the bioretention cell.

### Step 8: Select Plants and Mulch

Plants are an integral element of the bioretention system's pollutant removal and water filtration process. Plant roots aid in the physical and chemical bonding of soil particles necessary to form stable aggregates, improve soil structure, and increase infiltration capacity. Vegetated soils are more capable of more effective degradation, removal, and mineralization of total petroleum hydrocarbons, polycyclic aromatic hydrocarbons, pesticides, chlorinated solvents, and surfactants than are nonvegetated soils (USEPA, 2000).

The primary design considerations for plant selection include the following:

1. Soil moisture conditions: Soil moisture conditions will vary widely within the bioretention facility from saturated (bottom of cell) to relatively dry (rim of cell), as well as over time. Therefore, the predominant plant material utilized should be facultative species adapted to stresses associated with both wet and dry conditions (MDER, 2002). In some cases, the in situ soil can be ripped and amended so that vegetation can grow.
2. Pollutant loadings: Since bioretention is often specified for use in impaired and/or nutrient-sensitive watersheds, strategic use of particular plants for phytoremediation purposes is crucial. Plants should tolerate typical pollutants and loadings from the surrounding land uses.
3. Above- and below-ground infrastructure in and near the bioretention facility: Plant selection should consider the surrounding conditions, including light pollution tolerance, wind, and above- and below-ground utilities. Slotted or perforated pipes should be more than 5 feet away from tree locations. Plants with taproots should not be used.
4. Adjacent plant communities and potential invasive species control.
5. Site distances and setbacks for roadway applications.
6. Visual buffering: Plants can be used to buffer structures from roads, enhance privacy among residences, and provide an aesthetic amenity for the site.
7. Aesthetics: Visually pleasing plant designs add to the property and encourage community and homeowner acceptance. Public education and participation in the plant selection and design should be encouraged to promote greater involvement in long-term care.
8. Grass may be used; however, grassed cells must be sodded (not seeded), and the sod must not be grown in soil that has an impermeable layer, such as clay.

Planting design will vary with the surrounding landscape context and design objectives. For example, the use of plants in bioretention areas could replicate a variety of native terrestrial ecosystems, including forests, ornamental gardens, meadows, hedgerows, and wetlands, as well as wildlife habitats.

A minimum of one tree, three shrubs, and three herbaceous species should be incorporated in the bioretention planting plan unless it is a grassed cell. A diverse plant community is necessary to avoid susceptibility to insects and disease. A recommended minimum planting density is 400 stems/acre. Bacteria die-off occurs at the surface where stormwater is exposed to sunlight and the soil can dry out. Therefore, it is best for bioretention cells to not be too densely vegetated in order to allow greater exposure to sunlight and consequent die-off of bacteria (NCCE 2007).

The plants selected should be able to tolerate typical stormwater pollutant loads, variable (often very dry) soil moisture, temporary submergence, and extended wet conditions. Consult a design profession for the selection of plants.

To increase survival rates and ensure quality of plant materials, the following general guidelines for plantings within bioretention facilities are recommended:

- All plant material should conform to the standards of the current edition of American Standards for Nursery Stock as approved by the American Standards Institute, Inc. All plant grades shall be those established by the current edition of American Standards for Nursery Stock [http://www.anla.org/applications/Documents/Docs/ANLAStandard2004.pdf].
- All plant materials should have normal, well-developed branches and vigorous root systems, and be free from physical defects, plant diseases, and insect pests.
- All plant materials should be tagged for identification when delivered.
- Optimum planting time is fall. Winter planting is acceptable. Spring is acceptable but will require more summer watering than fall planting. Summer planting is the least desirable, as it drastically increases plant mortality and requires regular watering immediately following installation.
- Plant size should be no less than 2.5″ diameter at breast height for trees; 3-gallon for shrubs; and 1-quart for herbaceous plants.
- Woody vegetation should not be planted at inflow locations.
- For best survival, trees should be planted with the top of the root ball partially out of the media. They should be planted to have from 1/3 to 1/2 of the root ball within the media. This would leave from 2/3 to 1/2 of the root ball above the media.

Local jurisdictions often have specific guidelines for the types and location of trees and other landscape plants planted along public streets or rights-of-way. Additionally, local landscape ordinances must be followed. Contact local authorities to determine if there are guidelines or restrictions to consider when making plant selections for your project.

The mulch layer plays an important function in the performance of the bioretention system by reducing weed establishment; regulating soil temperatures and moisture; reducing soil compaction from rainfall; preventing erosion; and promoting an environment suitable for soil microorganisms at the mulch/soil interface (important for filtering nutrients and other pollutants). Mulches prevent soil and possible fungi from splashing on the foliage, reducing the likelihood of soil-borne diseases (Evans, 2000). Mulch serves as a pretreatment layer by trapping the finer sediments that remain suspended after the primary pretreatment. Additionally, most attenuation of heavy metals in bioretention facilities occurs in the first 1-2 inches of the mulch layer (Hinman, 2005). Other considerations related to mulch are these:

- Mulch should be free of weed seeds, soil, roots, and other material that is not bole or branch wood or bark.
- Use commercially available double- or triple-shredded hardwood mulch. This mulch has been found to be less likely to wash away than other forms of mulch (such as pine).
- Mulch depth depends on the type of material used and the drainage and moisture-holding capacity of the soil. A 2-4 inch layer (after settling) is adequate for most applications. Excessive application of mulch can result in a situation where the plants are growing in the mulch and not the soil. Over-mulched plants are easily damaged during periods of drought stress. Mulching in an area that is poorly drained can aggravate the condition (Evans, 2000).
- Mulch can be applied any time of year; however, the best time to mulch is late spring after the soil has warmed.
- Mulch should be at least 6 months old (12 months is ideal).
- It should be placed uniformly, about 3 inches deep.
- Mulch should be renewed as needed to maintain a 2-4″ depth; on previously mulched areas, apply a one-inch layer of new material. It should be added 1-2 times per year and completely removed/replaced once every two years.

## Siting Considerations

Some considerations for selecting a stormwater-management practice are the drainage area the practice will need to treat, the slopes both at the location of the practice and the drainage area, soil and subsurface conditions, and the depth of the seasonably high groundwater table. Bioretention can be applied on many sites, with its primary restriction being the need to apply the practice on small sites.

### Drainage Area

Bioretention areas should, in general, be used on small sites (i.e., 5 acres or less). When used to treat larger areas, they tend to clog. In addition, it is difficult to convey flow from a large area to a bioretention area.

### Slope

Bioretention areas are best applied to relatively shallow slopes (usually about 5 percent). However, sufficient slope is needed at the site to ensure that water that enters the bioretention area can be connected with the storm drain system. These stormwater-management practices are most often applied to parking lots or residential landscaped areas, which generally have shallow slopes.

### Soils/Topography

Bioretention areas can be applied in almost any soils or topography, since runoff percolates through a man-made soil bed and is returned to the stormwater system.

### Groundwater

Bioretention should be separated somewhat from the groundwater to ensure that the groundwater table never intersects with the bed of the bioretention facility. This design consideration prevents possible groundwater contamination.

### Design Variations

One design alternative to the traditional bioretention practice is the use of a "partial exfiltration" system, used to promote groundwater recharge. Other design modifications may make this practice more effective in arid or cold climates.

#### *Partial Exfiltration*

In one design variation of the bioretention system, the underdrain is installed on only part of the bottom of the system. This design alternative allows for some infiltration, with the underdrain acting as more of an overflow. This system can be applied only when the soils and other characteristics are appropriate for infiltration (see *Infiltration Trench* and *Infiltration Basin*).

## Common Problems

Bioretention areas have a few limitations. Bioretention areas cannot be used to treat a large drainage area, limiting their usefulness for some sites. In addition, although the practice does not consume a large amount of space, incorporating bioretention into a parking lot design may reduce the number of parking spaces available if islands were not previously included in the design.

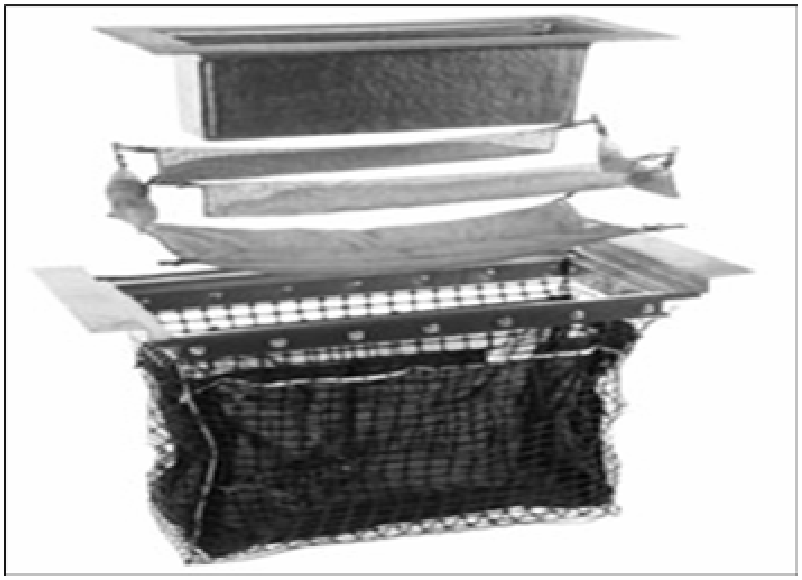
## Maintenance

Common maintenance activities include re-mulching, treating diseased trees and shrubs, and mowing turf areas.

Newly planted vegetation should be watered regularly until properly established.

Erosion issues should be addressed immediately.

# Catch Basin Inserts



## Practice Description

Catch basins, also known as storm drain inlets and curb inlets, are inlets to the storm drain system. They typically include a grate or curb inlet and a sump to capture sediment, debris, and pollutants. Catch basins are used in combined sewer overflow  watersheds to capture floatables and settle some solids, and they act as pretreatment for other treatment practices by capturing large sediments. The effectiveness of catch basins, that is, their ability to remove sediments and other pollutants, depends on their design (e.g., the size of the sump) and on maintenance procedures to regularly remove accumulated sediments from the sump.

Inserts designed to remove oil and grease, trash, debris, and sediment can improve the efficiency of catch basins. Some inserts are designed to drop directly into existing catch basins, while others may require retrofit construction.

## Planning Considerations

Though they are used in drainage systems throughout the United States, many catch basins are not ideally designed for sediment and pollutant capture. Catch basins are ideally used as pretreatment to another stormwater-management practice. Retrofitting existing catch basins may substantially improve their performance. A simple retrofit option is to ensure that all catch basins have a hooded outlet to prevent floatable materials, such as trash and debris, from entering the storm drain system. Catch basin inserts for both new development and retrofits at existing sites may be preferred when available land is limited, as in urbanized areas.

## Design Criteria

The performance of catch basins is related to the volume in the sump (i.e., the storage in the catch basin below the outlet). Lager et al. (1997) described an "optimal" catch basin sizing criterion, which relates all catch basin dimensions to the diameter of the outlet pipe (D):

- The diameter of the catch basin should be equal to 4D.
- The sump depth should be at least 4D. This depth should be increased if cleaning is infrequent or if the area draining to the catch basin has high sediment loads.
- The top of the outlet pipe should be 1.5D from the bottom of the inlet to the catch basin.

Catch basins can also be sized to accommodate the volume of sediment that enters the system. Pitt et al., (1997) proposed a sizing criterion based on the concentration of sediment in stormwater runoff. The catch basin is sized, with a factor of safety, to accommodate the annual sediment load in the catch basin sump. This method is preferable where high sediment loads are anticipated, and where the optimal design described above is suspected to provide little treatment.

The basic design should also incorporate a hooded outlet to prevent floatable materials and trash from entering the storm drain system. Adding a screen to the top of the catch basin would not likely improve the performance of catch basins for pollutant removal, but it would help capture trash entering the catch basin (Pitt et al., 1997).

Several varieties of catch basin inserts exist for filtering runoff. One insert option consists of a series of trays, with the top tray serving as an initial sediment trap, and the underlying trays composed of media filters. Another option uses filter fabric to remove pollutants from stormwater runoff. Yet another option is a plastic box that fits directly into the catch basin. The box construction is the filtering medium. Hydrocarbons are removed as the stormwater passes through the box, while trash, rubbish, and sediment remain in the box itself as stormwater exits. These devices have a very small volume, compared to the volume of the catch basin sump, and would typically require very frequent sediment removal. Bench test studies found that a variety of options showed little removal of total suspended solids, partially due to scouring from relatively small (6-month) storm events (ICBIC, 1995).

One design adaptation of the standard catch basin is to incorporate infiltration through the catch basin bottom. Two challenges are associated with this design. The first is potential groundwater impacts, and the second is potential clogging, preventing infiltration. Infiltrating catch basins should not be used in commercial or industrial areas, because of possible groundwater contamination. While it is difficult to prevent clogging at the bottom of the catch basin, it might be possible to incorporate some pretreatment into the design.

### Drainage Area

The total maximum drainage area should be 5,000 square feet (+5%) per unit for new development projects and 7,000 feet per unit for redevelopment projects.

### Accessibility

The insert should be located so that is it readily accessible for maintenance requirements and so that it will not be blocked by parked vehicles.

## Common Problems

Even ideally designed catch basins cannot remove pollutants as well as structural stormwater-management practices, such as wet ponds, sand filters, and stormwater wetlands.

Unless frequently maintained, catch basins can become a source of pollutants through resuspension.

Catch basins cannot effectively remove soluble pollutants or fine particles.

## Maintenance

Typical maintenance of catch basins includes trash removal (if a screen or other debris-capturing device is used) and removal of sediment using a vacuum truck. Operators need to be properly trained in catch basin maintenance. Maintenance should include keeping a log of the amount of sediment collected and the date of removal. Some cities have incorporated the use of geographic information systems to track sediment collection and to optimize future catch basin cleaning efforts.

One study (Pitt, 1985) concluded that catch basins can capture sediments up to approximately 60 percent of the sump volume. When sediment fills greater than 60 percent of their volume, catch basins reach steady state. Storm flows can then re-suspend sediments trapped in the catch basin, and will bypass treatment. Frequent clean-out can retain the volume in the catch basin sump available for treatment of stormwater flows.

At a minimum, catch basins should be cleaned once or twice per year (Aronson et al., 1993). In some regions, it may be difficult to find environmentally acceptable disposal methods for collected sediments. The sediments may not always be land-filled, land-applied, or introduced into the sanitary sewer system due to hazardous waste, pretreatment, or groundwater regulations. This is particularly true when catch basins drain runoff from hot-spot areas.

# Sand and Organic Filters

## Practice Description

Sand filters are usually designed as two-chambered stormwater practices: the first is a settling chamber, and the second is a filter bed filled with sand or another filtering media. As stormwater flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as stormwater flows through the filtering medium. There are several modifications of the basic sand filter design, including the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and multi-chamber treatment train. All of these filtering practices operate on the same basic principle. Modifications to the traditional surface sand filter were made primarily to fit sand filters into more challenging design sites (e.g., underground and perimeter filters) or to improve pollutant removal (e.g., organic media filter).

## Planning Considerations

Sand filters have been a proven technology for drinking water treatment for many years and more recently have been demonstrated to be effective in removing urban stormwater pollutants including total suspended solids, biological oxygen demand, fecal coliform, hydrocarbons, and metals. Since sand filters can be located underground, they can also be used in areas with limited surface space.

Sand filters are designed primarily for water quality enhancement; flow volume control is typically a secondary consideration. They are generally applied to land uses with a large fraction of impervious surfaces. Although an individual sand filter can handle only a small contributing drainage basin, multiple units can be dispersed throughout a large site. Sand filters can be of open basin design or of buried trench design (a closed basin). Sand filters typically employ underdrain systems to collect and discharge treated stormwater but can also be designed as infiltration type systems when located in soils with sufficient permeability or infiltration rates.

Sand filters are a good option to achieve water quality goals in retrofit studies where space is limited, because they consume very little surface space and have few site restrictions. It is important to note, however, that sand filters cannot treat a very large drainage area. Using small-site BMPs in a retrofit may be the only option for a retrofit study in a highly urbanized area, but it is expensive to treat the drainage area of an entire watershed using many small-site practices, as opposed to one larger facility such as a pond.

## Design Criteria

### Converting Erosion- and Sediment-Control Devices

A basin used for construction erosion and sediment control can be converted into an open basin-type sand filter if all sediment is removed from the basin prior to construction of the sand filter and proper sand filter design is followed. Buried trench-type sand filters are typically newly constructed after site construction and not placed in modified site construction sediment- and erosion-control basins. Sand filters are not to be brought on-line until site construction activities are completed and groundcover is fully stabilized.

### Drainage Area

The maximum contributing drainage area to an individual sand filter shall be less than 5 acres; however, 1 acre or less is recommended. Multiple sand filters can be used throughout a development to provide treatment for larger sites.

### Slope

Sand filters can be used on sites with slopes up to about 6 percent. It is challenging to use most sand filters in very flat terrain because they require a significant amount of elevation drop, or head (about 5 to 8 feet), to allow flow through the system. One exception is the perimeter sand filter, which can be applied with as little as 2 feet of head.

### Soils/Topography

When sand filters are designed as a stand-alone practice, they can be used on almost any soil because they can be designed so that stormwater never infiltrates into the soil or interacts with the groundwater. Alternatively, sand filters can be designed as pretreatment for an infiltration practice, where soils do play a role.

### Groundwater

Designers should provide at least 2 feet of separation between the bottom of the filter and the seasonally high groundwater table. This design feature prevents both structural damage to the filter and possibly, though unlikely, groundwater contamination.

### Pretreatment

Erosive velocities and high sediment loads are a concern with sand filters. Sediment can quickly blind a sand filter and cause premature failure of the BMP. Two devices that reduce the impact of these factors on the sand filter are flow splitter devices and forebays.

Flow beyond the design flow can overload the hydraulic capacity of a sand filter (usually resulting in an overflow), cause erosion in open basin sand filters, and deliver more sediment to the sand filter than is necessary. Because of these issues, sand filters are required to be designed “off-line,” meaning only the design volume of the stormwater flow is sent from the conveyance system into the treatment unit, and the excess is diverted.

A forebay or sedimentation chamber is required on all sand filters, to protect the sand filter from clogging due to sediment and to reduce the energy of the influent flow. The forebay can be in the form of an open basin (typical with an open basin sand filter design), or a subsurface concrete chamber (typical with a buried trench design). The forebay must contain ponded water (not be drained down with the sand filter). If a subsurface concrete chamber is provided, appropriate means of removing accumulated sediment must be demonstrated. Since individual sand filters treat relatively small volumes of stormwater and the design of the forebay is a percent of the total design volume, the forebay can also be very small. The minimum width (measurement parallel to flow direction) of the sedimentation chamber or forebay shall be 1.5 feet.

Following the sedimentation chamber or forebay, stormwater flow may be distributed over the surface of the sand filter in a variety of ways. In an open design, it could flow onto the sand filter as sheet flow via a level spreader. Depending on the geometry of the sand filter, however, that may not provide enough flow distribution to prevent overloading and clogging of the leading edge of the sand filter. One common method of distributing flow onto sand filters, both the open basin and buried trench types, is through the use of a pipe distribution or weir system.

## Length, Width and Geometry

The area required for a sand filter device is calculated similar to many other BMP types. Since a sand filter must be completely drained within 40 hours, the ponding depth is a function of the media’s infiltration rate. Once the ponding depth is known, the surface area can be calculated based on the design volume.

A sand filter consists of two parts, the sedimentation basin (which serves as a sort of forebay) and the sand filter itself. These two parts are collectively referred to as the “sand filter.” An open basin type sand filter can be rectangular, square, circular, or irregular. Buried trench systems (closed basin systems) are often very rectangular, approaching linear. The important factor is that incoming stormwater is distributed relatively evenly over the surface of the sand filter. The following series of steps are used to determine the appropriate sand filter size.

*Step 1:* Compute the water quality volume (WQV) using Schueler’s Simple Method, as described in Chapter 3 and summarized below, and the adjusted water quality volume ($WQV_{Adj}$) as defined below (CWP, 1996).

$$WQV(ft^3) = \frac{R_v(unitless)}{1} x \frac{A_D(acres)}{1} x \frac{43{,}560\,ft^2}{1Acre} x \frac{R_D inchRain}{1} x \frac{ft}{12in}$$

$$WQV_{Adj}(ft^3) = (0.75)WQV$$

- WQV: Water Quality Volume ($ft^3$). This is used to size the surface areas of the sedimentation chamber and the sand filter.

- $WQV_{Adj}$: Adjusted Water Quality Volume ($ft^3$). This is used as the volume that must be contained between the sedimentation chamber and the sand filter (above the sand).
- $A_D$: Drainage area to the sand filter (acres)
- $R_v$: Volumetric runoff coefficient (unitless) = 0.05 + 0.009(%Imp)
  - %Imp: Percent of impervious of land draining to the sand filter

*Step 2*: Determine the maximum and average head on the sand filter, and determine the surface areas of the sand filter and the sedimentation chamber.

*Maximum Head on the Sand Filter*

- $h_{MaxFilter}$(ft): Maximum head on the sand filter (ft). This head is typically measured from the top of the overflow weir, which separates the sediment chamber from the sand chamber, to the top of the sand and should be no more than 6 feet. Choose the maximum head so that the following equation is true:

$$h_{MaxFilter}\,(ft) = \frac{WQV_{Adj}\,(ft^3)}{A_S\,(ft^2) + A_f\,(ft^2)}$$

- $A_s$: Surface area of the sedimentation basin ($ft^2$)
- $A_f$: Surface area of the sand filter bed ($ft^2$)

$$h_A(ft) = \frac{h_{MaxFilter}(ft)}{2}$$

- $h_A$ = Average head (ft). The average head on the sand filter is approximately equal to the average head on the sedimentation basin.

*Sedimentation Basin Surface Area:*

The minimum surface area for the sedimentation basin is determined by the Camp Hazen Equation:

$$A_s\,(ft^2) = -\frac{Q_o\left(\frac{ft^3}{\sec}\right)}{w\left(\frac{ft}{\sec}\right)}\,x\ln(1-E)$$

$$A_S\,(ft^2) = -\frac{\left(\frac{WQV(ft^3)}{24hr}\right)x\left(\frac{1hr}{3600\sec}\right)}{0.0004\left(\frac{ft}{\sec}\right)}\,x\ln(1-0.9)$$

$$A_S\,(ft^2) = 0.066WQV(ft^2)$$

$$A_S\,(ft^2) = 0.066\left[\frac{R_v(unitless)}{1}\,x\,\frac{A_D(Acres)}{1}\,x\,\frac{43{,}560(ft^2)}{(Acre)}\,x\,\frac{R_D(in)}{1}\,x\,\frac{1(ft)}{12(in)}\right](ft^2)$$

$$A_S\,(ft^2) = [240 * R_v(unitless) * A_D(acres)] * R_D\left(ft^2\right)$$

- $Q_{o:}$ Average rate of outflow from the sedimentation chamber ($ft^3$/sec). (CWP, 1996)
- E: Trap efficiency of the chamber = 0.9 (unitless)
- w: Settling velocity of particle. Assume that the particles collected by the filter are 20 microns in diameter. For 20 microns, w = 0.0004 (ft/sec). This varies depending on the imperviousness of the land draining to the sand filter, but the value presented here is representative of most situations.

*Sand Filter Bed Surface Area:*
The minimum surface area for the sand filter bed is determined by Darcy's Law:

$$A_f\,(ft^2) = \frac{(WQV)(d_F)}{(k)(t)(h_A + d_F)}$$

- $d_F$: Depth of the sand filter bed, (ft). This should be a minimum of 1.5 ft.
- k: Coefficient of permeability for the sand filter bed = 3.5 (ft/day).
- t: Time required to drain the WQV through the sand filter bed (day). This time should be 40 hours (1.66 days).**Error! Bookmark not defined.**
- $h_A$: Average head (ft).
  - Determine the average head of water above the sand filter. The average head above the sand filter is half of the maximum head on the filter.

*Step 3:* Ensure that the water quality volume is contained:

- Ensure that this combination of variables will contain the required volume ($WQV_{Adj}$ ($ft^3$)):
  - $\left[A_f\,(ft^2) + A_s\,(ft^2)\right] x \left[h_{MaxFilter}(ft)\right] \geq WQV_{Adj}\,(ft^3)$

*Step 4*: Additional design requirements:
For underground sand filters, provide at least 5 feet of clearance between the surface of the sand filter and the bottom of the roof of the underground structure to facilitate cleaning and maintenance.

### *Example Calculation*

Design a sand filter to treat the first inch of water from a 1-acre site that is 100% impervious. There is 720 $ft^2$ of space available for this underground project.

**Step 1 – Compute water quality volume**

- Rv = 0.05 + 0.9(%Imp) = 0.05 + 0.009(100) = 0.95
- $WQV(ft^3) = \frac{0.95(unitless)}{1} x \frac{1(acres)}{1} x \frac{43{,}560\,ft^2}{1Acre} x \frac{1inchRain}{1} x \frac{ft}{12in} = 3{,}449\,ft^3$

  $WQV_{Adj}\,(ft^3) = (0.75)(3{,}449) = 2{,}587(ft^3)$

**Step 2 – Determine filter bed and sedimentation basin surface areas with respect to water quality volume and maximum head**

- $h_{MaxFilter}(ft) = \frac{2{,}586(ft^3)}{A_S(ft^2) + A_f(ft^2)}$, for maximum heads between 0.5 foot and 6 feet, the following combinations of variables will work:

| **$H_{MaxFilter}$** (ft) | **$WQV_{adj}$** (cu ft) | **$A_s + A_f$** (sq ft) |
|---|---|---|
| 0.5 | 2,586 | 5,172 |
| 1.0 | 2,586 | 2,586 |
| 1.5 | 2,586 | 1,724 |
| 2.0 | 2,586 | 1,293 |
| 3.0 | 2,586 | 862 |
| 4.0 | 2,586 | 647 |
| 5.0 | 2,586 | 517 |
| 6.0 | 2,586 | 431 |

- $A_s(ft^2)$ = 240*0.95*1 = 228 ($ft^2$) – This is the minimum value for the area of the sedimentation basin. Larger basins are acceptable.

- Choose a combination of $A_f$ and $h_A$ to meet the available space on-site. Typically, the sedimentation chamber and the sand filter bed should be approximately the same size. If 720 $ft^2$ of space is available, then $A_s$ and $A_f$ can both be 360 $ft^2$, and the maximum head on the sand filter is interpolated to be 3.6 ft. The average head is half of the maximum head, 1.8 ft. Check to ensure that the minimum area for the sand filter is attained:

  - $A_f(ft^2) = \frac{(3{,}449(ft^2))(1.5(ft))}{(3.5(ft/day))(1.66(day))(1.8(ft) + 1.5(ft))} = 270\, ft^2$.

  This is the minimum value for the area of the sand filter. Larger sand filters are acceptable, and therefore the chosen combination of variables is acceptable for this design.

- There are several combinations of surface areas and depths that would be acceptable for this design. In this example:
  - $A_f$ = 360 $ft^2$
  - $A_s$ = 360 $ft^2$
  - $h_{MaxFilter}$ = 3.6 ft
  - $h_A$ = 1.8 ft

**Step 3 – Verify volumes**

- $2{,}592(ft^3) = [360(ft^2) + 360(ft^2)]x[3.6(ft)] \Rightarrow \geq 2{,}586(ft^3)$

**Step 4 – Check additional design criteria**

- o Because this is an underground project, sufficient access must be provided to facilitate cleaning and maintenance.

### Treatment

Treatment design features help enhance the ability of a stormwater-management practice to remove pollutants. In filtering systems, designers should provide at least 75 percent of the water quality volume in the practice, including both the sand chamber and the sediment chamber. The filter bed should be sized using Darcy's Law, which relates the velocity of fluids to the hydraulic head and the coefficient of permeability of a medium. In sand filters, designers should select a medium-sized sand as the filtering medium.

### Media Requirements

The media in the sand filter shall be cleaned, washed, coarse masonry sand such as ASTM C33. The sand particles shall be less than 2 mm average diameter. The filter bed shall have a minimum depth of 18 inches, with a minimum depth of sand above the drainage pipe of 12 inches. The medium for organic filtering can be a combination of 50% peat and 50% sand or compost-only filter, both with a minimum depth of 18 inches. The peat/sand filter should be installed over a 6-inch layer of sand.

### Conveyance

Conveyance of stormwater runoff into and through the filter should be conducted safely and in a manner that minimizes erosion potential. Ideally, some stormwater treatment can be achieved during conveyance to and from the filter. Since filtering practices are usually designed as "off-line" systems, meaning that they have the smaller water quality volume diverted to them only during larger storms, using a flow splitter, which is a structure that bypasses larger flows to the storm drain system or to a stabilized channel. One exception is the perimeter filter. In this design, all flows enter the system, but larger flows overflow to an outlet chamber and are not treated by the practice. All filtering practices, with the exception of exfilter designs, are designed with an underdrain below the filtering bed. An underdrain is a perforated pipe system in a gravel bed, installed on the bottom of filtering practices and used to collect and remove filtered runoff.

### Drainage Considerations

The sand filter chamber shall drain completely within 40 hours. The length of time that it takes to drain the media of a filter is controlled by the infiltration rate of the media (or possibly the infiltration rate of the in situ soil if the system is designed as an infiltration type system).

### Landscaping

Landscaping can add to both the aesthetic value and the treatment ability of stormwater practices. In sand filters, little landscaping is generally used on the practice, although surface sand filters and organic media filters may be designed with a grass cover on the surface of the filter. In all filters, designers need to ensure that the contributing drainage has dense vegetation to reduce sediment loads to the practice.

## Common Problems

When the filtering capacity diminishes substantially (e.g., when water ponds on the surface for more than 40 hours), remedial actions must be taken. One possible cause of this problem is that collection pipe systems have become clogged. Annual flushing of pipe clean-outs is recommended to facilitate unclogging of the pipes without disturbing the filter area. If the water still ponds above the sand filter bed for more than 40 hours, the top few inches of media should be removed and replaced with fresh media. The removed sediments should be disposed of in an acceptable manner (e.g., landfill). If the problem still persists, more extensive rebuilding is required.

## Maintenance

Typical annual maintenance requirements are:

- Check to see that the filter bed is clean of sediments, and the sediment chamber is no more than one-half full of sediment; remove sediment if necessary.
- Make sure that there is no evidence of deterioration, sailing, or cracking of concrete.
- Inspect grates (if used).
- Inspect inlets, outlets, and overflow spillway to ensure good condition and no evidence of erosion.
- Repair or replace any damaged structural parts.
- Stabilize any eroded areas.
- Ensure that flow is not bypassing the facility.

# Vegetated Filter Strip

## Practice Description

Vegetated filter strips (grassed filter strips, filter strips, and grassed filters) are vegetated surfaces that are designed to treat sheet flow from adjacent surfaces. Filter strips function by slowing runoff velocities and filtering out sediment and other pollutants, and by providing some infiltration into underlying soils. Filter strips were originally used as an agricultural treatment practice, and have more recently evolved into an urban practice. With proper design and maintenance, filter strips can provide relatively high pollutant removal. One challenge associated with filter strips, however, is that it is difficult to maintain sheet flow, so the practice may be "short circuited" by concentrated flows, receiving little or no treatment.

## Planning Considerations

Filter strips are applicable in most regions, but are restricted in some situations because they consume a large amount of space relative to other practices. Filter strips are best suited to treating runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. They are also ideal components of the "outer zone" of a stream buffer (see *Riparian/Forested Buffer Practice*), or as pretreatment to a structural practice. This recommendation is consistent with recommendations in the agricultural setting that filter strips are most effective when combined with another practice (Magette et al., 1989).

### Urban Areas

Urban areas are densely developed urban areas in which little pervious surface exists. Filter strips are impractical in ultra-urban areas because they consume a large amount of space.

### Stormwater Hot Spots

Stormwater hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. A typical example is a gas station. Filter strips should not receive hot-spot runoff, because the practice encourages infiltration. In addition, it is questionable whether this practice can reliably remove pollutants. Therefore, it should definitely not be used as the sole treatment of hot-spot runoff.

### Stormwater Retrofit

A stormwater retrofit is a stormwater-management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Filter strips are generally a poor retrofit option because they consume a relatively large amount of space and cannot treat large drainage areas.

## Design Criteria

### Siting Considerations

In addition to the restrictions and modifications to adapting filter strips to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. The following section provides basic guidelines for siting filter strips.

Recommended distances (for the location of the filter strip from surface waters) depend on the applicable rules:

– An engineered filter strip may not be placed within either inner zone of a riparian buffer. However, it may be placed within a stormwater setback/buffer.

– Wetlands will be allowed within the filter strip only on a case-by-case basis.

#### *Drainage Area*

Typically, filter strips are used to treat very small drainage areas. The limiting design factor, however, is not the drainage area the practice treats but the length of flow leading to it. As stormwater runoff flows over the ground’s surface, it changes from sheet flow to concentrated flow. Rather than moving uniformly over the surface, the concentrated flow forms rivulets that are slightly deeper and cover less area than the sheet flow. When flow concentrates, it moves too rapidly to be effectively treated by a grassed filter strip. (The use of a level spreader may be helpful in cases with concentrated flows.) Furthermore, this concentrated flow can lead to scouring. As a rule, flow concentrates within a maximum of 75 feet for impervious surfaces and 150 feet for pervious surfaces (CWP, 1996). Using this rule, a filter strip can treat one acre of impervious surface per 580-foot length.

### *Slope*

Filter strips should be designed on slopes between 2 and 6 percent. Greater slopes than this would encourage the formation of concentrated flow. Except in the case of very sandy or gravelly soil, runoff would pond on the surface of slopes flatter than 2 percent, creating potential mosquito-breeding habitat.

### *Soils /Topography*

Filter strips should not be used on soils with high clay content, because they require some infiltration for proper treatment. Very poor soils that cannot sustain a grass cover crop are also a limiting factor.

### *Groundwater*

Filter strips should be separated from the groundwater by between 2 and 4 ft to prevent contamination and to ensure that the filter strip does not remain wet between storms.

## Design Considerations

Filter strips appear to be a minimal design practice because they are basically no more than a grassed slope. However, some design features are critical to ensure that the filter strip provides some minimum amount of water quality treatment.

- A pea gravel diaphragm should be used at the top of the slope. The pea gravel diaphragm (a small trench running along the top of the filter strip) serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip.
- The filter strip should be designed with a pervious berm of sand and gravel at the toe of the slope. This feature provides an area for shallow ponding at the bottom of the filter strip. Runoff ponds behind the berm and gradually flows through outlet pipes in the berm. The volume ponded behind the berm should be equal to the water quality volume. The water quality volume is the amount of runoff that will be treated for pollutant removal in the practice. Typical water quality volumes are the runoff from a 1-inch storm or ½-inch of runoff over the entire drainage area to the practice.
- The filter strip should be at least 25 feet long to provide water quality treatment.
- Designers should choose a grass that can withstand relatively high-velocity flows and both wet and dry periods.
- Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.

## Common Problems

Filter strips have several limitations related to their performance and space consumption:

- The practice has not been shown to achieve high pollutant removal.
- Filter strips require a large amount of space, typically equal to the impervious area they treat, making them often infeasible in urban environments where land prices are high.
- If improperly designed, filter strips can allow mosquitoes to breed.
- Proper design requires a great deal of finesse, and slight problems in the design, such as improper grading, can render the practice ineffective in terms of pollutant removal.

## Maintenance

- Immediately after the filter strip is established, grass will be watered twice weekly, if needed, until the plants become established (commonly six weeks).
- Once a year, the filter strip will be reseeded to maintain a dense growth of vegetation
- Stable groundcover will be maintained in the drainage area to reduce the sediment load to the vegetation.
- Every two weeks during the growing season, the filter strip will be mowed. Turf grass should not be cut shorter than 3 to 5 inches and may be allowed to grow as tall as 12 inches depending on aesthetic requirements (NIPC, 1993). Forested filter strips do not require this type of maintenance.
- Once a year, the soil will be aerated if necessary.
- Once a year, soil pH will be tested and lime will be added if necessary.

# Constructed Stormwater Wetland

## Practice Description

Stormwater wetlands provide an efficient biological method for removing a wide variety of pollutants (e.g. suspended solids, nutrients (nitrogen, N, and phosphorus, P), heavy metals, toxic organic pollutants, and petroleum compounds) in a managed environment.

Compared with wet ponds, sand filters, bioretention areas, and other stormwater BMPs, wetlands have the best median removal rate for total suspended solids (TSS), nitrate-nitrogen, ammonia-nitrogen, total phosphorus (TN), phosphate-phosphorus, and some metals. Stormwater wetlands can also be used to reduce pollution associated with high levels of fecal coliform and other pathogen contamination. Wetlands temporarily store stormwater runoff in shallow pools that support emergent and riparian vegetation. The storage, complex microtopography, and vegetative community in stormwater wetlands combine to form an ideal matrix for the removal of many pollutants. Stormwater wetlands can also effectively reduce peak runoff rates and stabilize flow to adjacent natural wetlands and streams.

Wetlands are effective sedimentation devices and provide conditions that facilitate the chemical and biological processes that cleanse water. Pollutants are taken up and transformed by plants and microbes, immobilized in sediment, and released in reduced concentrations in the wetland's outflow, as shown in Figure 1.

Plants improve water quality by slowing water flow and settling solids, transforming or immobilizing pollutants, and supplying reduced carbon and attachment area for microbes (bacteria and fungi). Dense strands of vegetation create the quiescent conditions that facilitate the physical, chemical, and biological processes that cleanse the stormwater. Many herbaceous wetland plants die annually. Because the dead plant material requires months or years to decompose, a dense layer of plant litter accumulates in the wetland. Like the living vegetation, the litter creates a substrate that supports bacterial growth and physically traps solids.

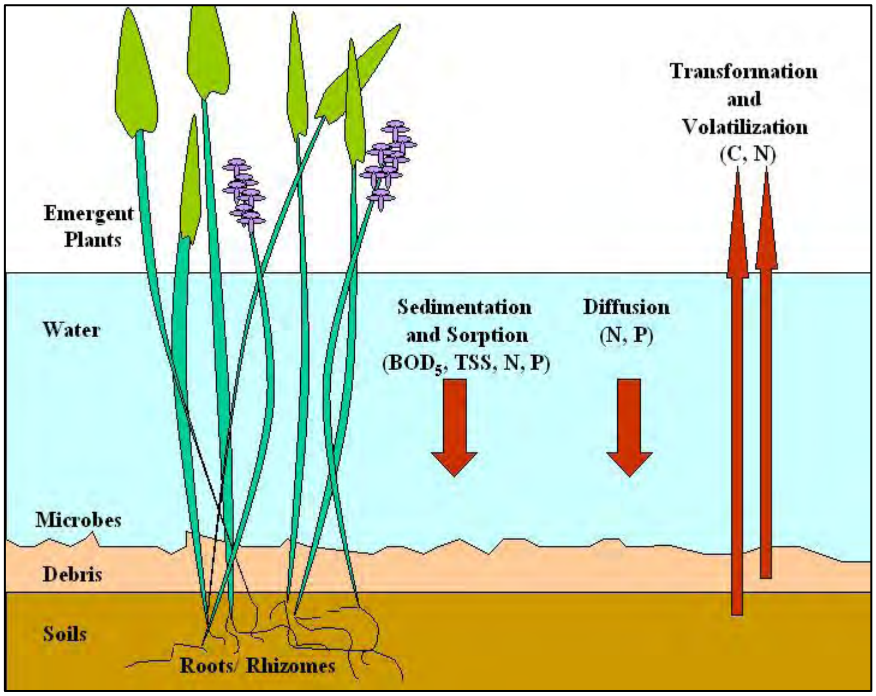



**Figure 1 Wetland Microbes, Plants and Soil Transform and Take up Pollutants from Stormwater**

Microorganisms, adhering to vegetation, roots, and sediment in the wetland, can decompose organic compounds and convert significant quantities of nitrate directly to nitrogen gas. Large amounts of nitrogen and phosphorus also can be incorporated in new soil and in the extra biomass of the wetland vegetation. Transformations can take place through both aerobic and anaerobic processes. For these reasons, maintaining the health of the vegetative community is critical for effective pollutant removal.

The ability of the emergent plants to settle and stabilize suspended solids in sediments and to reduce resuspension is important. The settling characteristic allows the wetland to remove pollutants such as phosphorus, trace metals, and hydrocarbons that are typically adsorbed to the surfaces of suspended particles.

Long-term data from stormwater wetlands indicate that treatment performance for parameters such as 5-day biochemical oxygen demand (BOD5), TSS, and TN typically does not deteriorate over the life of a stormwater wetland. The dissolved oxygen (DO) concentration in wetland outflows may be below 1.0 mg/L. Higher DO concentrations can be achieved by incorporating aeration techniques such as turbulent or cascading discharge zones, or mechanical mixing.

## Planning Considerations

Stormwater wetlands occupy somewhat more surface area than a wet detention pond, but have the potential to be better integrated aesthetically into a site design because of the abundance of aquatic vegetation. Stormwater wetlands require a drainage area sufficiently large, or adequate groundwater or surface water supplies, to provide year-round hydration. In sloping terrain, wetland cells can be arranged in series on terraces.

Stormwater wetlands are appropriately located at the lower parts of the development site. Careful planning is needed to be sure that sufficient water will be retained to sustain good wetland plant growth. Since water depths are shallower than in wet detention ponds, water loss by evaporation is an important concern.

Stormwater wetlands are designed in such a way that the distance the water flows from the entrance to the exit is maximized. This allows for sufficient contact time for pollutant removal.

## Design Criteria

### Converting Erosion- and Sediment-Control Devices

Often, the same basin can be used during construction as a sediment- and erosion-control device and later converted to a stormwater wetland. Before conversion, all accumulated sediment must be removed and properly disposed of; then, the appropriate modifications to the basin depth, geometry, and hydrology, as well as inlet and outlet structures, etc., must be made.

## Siting Considerations

In addition to the restrictions and modifications to adapting stormwater wetlands to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. The following section provides basic guidelines for siting wetlands.

### Drainage Area

Wetlands need sufficient drainage area to maintain the permanent pool. In humid regions, this is typically about 25 acres, but a greater area may be needed in regions with less rainfall.

### Slope

Wetlands can be used on sites with an upstream slope of up to about 15 percent. The local slope should be relatively shallow, however. While there is no minimum slope requirement, there does need to be enough elevation drop from the inlet to the outlet to ensure that hydraulic conveyance by gravity is feasible (generally about 3 to 5 feet).

### Soils/Topography

Wetlands can be used in almost all soils and geology.

### Nutrient Reduction

The wetland substrate contains a mixture of sediment, plants, water, and detritus that collectively remove multiple pollutants through a series of complementary physical, chemical, and biological processes. Stormwater wetlands are effective at reducing TSS, TN, and TP.

Some wetlands can be constructed as a pond/wetland system. In these cases, part of the BMP is a pond and part of it is a wetland. These systems are slightly less effective at nitrogen removal than wetland-only designs. In some cases, the pond/wetland systems provide additional benefits that warrant a less effective nitrogen removal BMP and therefore should be considered based on the priority of pollutant removal.

## Design Considerations

Design is a six-step process:

1) Understand basic layout concepts

2) Determine the volume of water to treat

3) Determine surface area and depth of each wetland zone

4) Select the soil media type

5) Select the appropriate outlet structure

6) Select plants

### Step 1: Understand Basic Layout Concepts

#### Stormwater Wetland Components

Stormwater wetlands consist of six primary components. Figure 2 provides a conceptual diagram, and brief descriptions are given below.

1. **Inlet**: This is where water enters the wetland. The inlet can be a swale, a pipe, a diverter box, sheet flow, or other method of transporting water to the wetland.

2. **Deep Pool:** This zone consists of permanent deep pools of water that retain water even during drought. Deep pools in a stormwater wetland are one of two types:

a. *Forebay:* The forebay is a deep pool that directly follows the inlet provides two important functions: (1) dissipates runoff velocity and energy and (2) collects gross solids and sediment to ease maintenance of the BMP. The forebay essentially acts as a pretreatment device for the stormwater wetland. The water flows out of the forebay and into the wetland. The entrance to the forebay is deeper than the exit of the forebay. This design will dissipate the energy of the water entering the system, and will also ensure that large solids settle out.

b. *Non-Forebay Deep Pools*: Other deep pools in the wetland are always full of water and are areas where rooted plants do not live. Submerged and floating plants may be used in this area, except around the wetland outlet device. The deep pool at the outlet should be non-vegetated to prevent clogging. Deep pools provide additional pollutant removal and storage volume as well as habitat for aquatic wildlife such as the mosquito-eating fish. Include a deep pool next to the outlet structure to allow for proper drawdown.

3. **Shallow water, “low marsh”**: Shallow water includes all areas inundated by the permanent pool to a depth of 3″-6″ with occasional drying during periods of drought. The shallow water zone provides a constant hydraulic connection between the inlet and outlet structure of the stormwater wetland. The top of the shallow water zone represents the top of the permanent pool elevation (PPE). Herbaceous plants, listed in Table 1, are recommended for this area because they are more efficient in the pollutant removal process and less likely to encourage mosquito growth.

4. **Shallow land, “high marsh” or “temporary inundation zone”**: This zone provides the temporary storage volume of the stormwater wetland. The top of the shallow land zone represents the top of the temporary pool elevation (TPE). The shallow land is wet only after a rain event, and rooted plants live in this zone. (See Table 1 at the end of this section for plant selection.) Shallow land in a wetland provides pollutant uptake, shade, and wildlife habitat and should be planted with vegetation able withstand irregular inundation and occasional drought.

5. **Upland**: These areas are never wet, are not a required element of wetland design, and can be eliminated if space is of concern. They may serve as an amenity or provide access for maintenance. Some wetlands have upland areas as an island in the center of the wetland.

6. **Outlet**: The outlet structure consists of a drawdown orifice placed at the top of the shallow water elevation so that stormwater accumulating in the shallow land area will be able to slowly draw down from the wetland. The outlet structure may also be designed to pass larger storm events, which will have a higher flow outlet at the proper elevation.

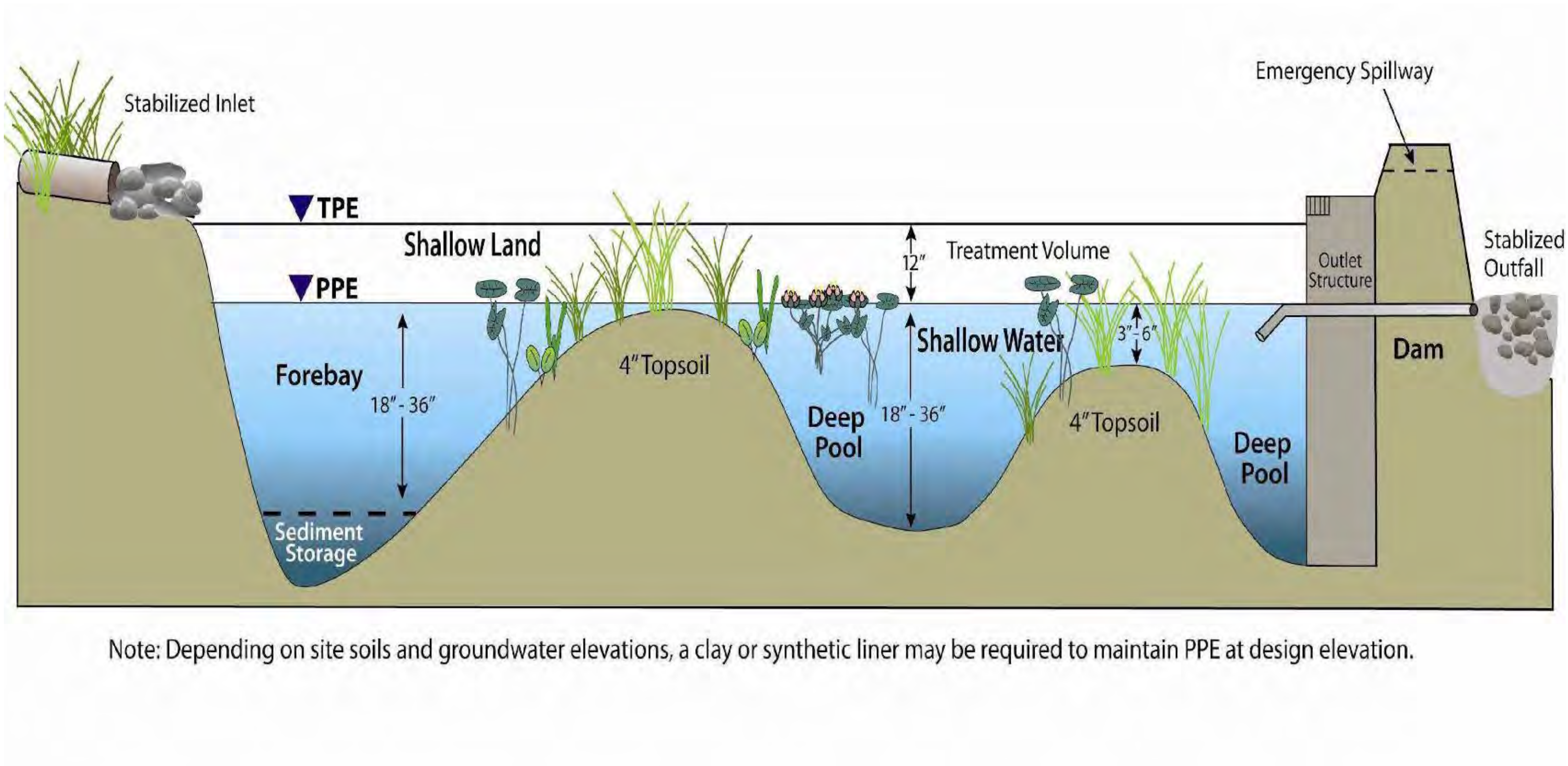



**Figure 2 Constructed Stormwater Wetland Conceptual Diagram**

## Step 2: Determine the Volume of Water to Treat

### Water Treatment Volume

A wetland is intended to treat the first flush (1″-1.5″) of a particular design storm. The Simple Method in Appendix A details the volumetric calculation.

### Contributing Drainage

There is no minimum or maximum for the drainage area. Instead, any drainage area that contributes a minimum volume of 3,630 cubic feet is allowed. Smaller volumes will be allowed on a case-by-case basis, though supporting calculations such as a water balance or other justification will be required.

### Siting Issues

Stormwater wetlands should not be located within existing jurisdictional wetlands or constructed as in-stream impoundments. If there are industrial or commercial land uses in the drainage area, accumulated pollutants may eventually increase environmental risk to wildlife (such as algae blooms). Typical pollutant loads found in residential and commercial settings are unlikely to cause this problem.

### Pretreatment Options

Wetlands and pond/wetland systems require the use of a forebay for pretreatment.

## Step 3: Determine Surface Area and Depth of Each Wetland Zone

Flow paths from inlet to outlet points within stormwater wetlands should be maximized. Internal berms and irregular shapes are often used to achieve recommended flow paths. The minimum length-to-width ratio shall be 1.5:1; however, 3:1 is highly recommended. Narrow, deep-water zones should be constructed at the wetland inlet and outlet to evenly distribute flow. Inlets also may incorporate pipe manifolds to enhance flow distribution. Deep-water zones perpendicular to the flow direction, and internal berms parallel to the flow, can also be used to reduce the potential for short-circuiting.

The total surface area of the deep-pool topographic zone should be broken into several micropools that are well dispersed throughout the wetland so that the distance for fish to travel within the shallow water zone to reach the entire wetland is minimized. One deep pool should be located at the entrance of the wetland, and one should be located at the exit. Other deep pools can be dispersed throughout the wetland.

*The geometric calculations for wetlands are provided below. As opposed to many other types of BMP designs, the permanent volume of water contained in the stormwater wetland is not part of the design calculations, but is merely a result of the breakdown of natural or engineered hydrologic zones and their respective depths.*

a. Determine Required Surface Area of Entire Wetland and Each Wetland Zone:

Two factors determine the surface area:

1) The watershed runoff volume that is to be contained ($Q_{Volume}$), and

2) The depth of water that plants can sustain for several days in the shallow land area ($D_{Plants}$), the depth of the temporary pool, up to 12 inches (Hunt and Doll, 2000).

The total surface area of the wetland is determined by the quotient of these variables. The surface area of each wetland zone is a percentage of the total required surface area.

Calculations for determining the surface areas of the various wetland zones are provided below.

• *Surface Area*: The total surface area of the wetland is

$$\frac{Q_{Volume}(ft^3)}{D_{Plants}(ft)} = \_\_\_ \text{ (SF)}$$

(Note: $D_{Plants}$ can be up to 12 inches.) This surface area, in square feet (SF), is distributed to the various wetland zones as outlined below:

- Deep Pools: Ideally, several deep pools should be provided throughout the wetland.
  - Non-Forebay: 5-10% of wetland surface
  - Forebay: 10% of wetland surface
- Shallow Water (low marsh): 40% of wetland surface.
- Shallow Land (high marsh): 30-40% of wetland surface (maximize if pathogens are target pollutant).
- Upland: This is an optional design element. If upland area is included, it will not replace any of the required calculated surface area.

b. Design Depth of Each Wetland Zone: Determine the appropriate depth for each wetland zone. The following depths are recommended for each wetland zone as illustrated in Figure 2:

- Deep Pools:
  - Non-Forebay: 18-36” (include one at the outlet structure for proper drawdown).
  - Forebay: 18-36” plus additional depth for sediment accumulation (deepest near inlet to dissipate energy, more shallow near the exit).
- Shallow Water (low marsh): 3-6”. A primary cause of wetland failure is designing this layer to be too deep.
- Shallow Land (high marsh): Up to 12”. This is the depth, $D_{Plants}$, used in the surface area calculation, and is also the depth of the temporary pool.
- Upland: Up to 4 feet above the shallow land zone.

c. Double Check the Volume: Ensure that the volume of the shallow land section can accommodate the treatment volume necessary for the wetland (as was calculated in Step 2). The shallow land zone acts as the temporary pool and contains the treatment volume after a rain event.

### Step 4: Select the Soil Media Type

A soil analysis should be conducted within the stormwater facility area to determine the viability of soils to ensure healthy vegetation growth and to provide adequate infiltration rates through the topsoil. For wetlands designed to utilize a clay or synthetic liner, at least four (4) inches of quality topsoil shall be added to the top of the liner to support plant growth. Imported or in situ soils may be amended with organic material, depending on soil analysis results, to enhance suitability as a planting media.

## Step 5: Select the Appropriate Outlet Structure

The outlet design must be accessible to operators, easy to maintain, and resistant to fouling by floating or submerged plant material or debris. Wetlands should have both low- and high-capacity outlets. High-capacity outlets, such as weir boxes or broadcrested spillways, should be provided unless bypasses are provided for storms in excess of the first flush volume. The low-capacity outlet is typically a drawdown orifice and should be able to draw down the temporary pool within 2-5 days. Multiple-outlet structures are often used to balance the volume control requirements and maintenance needs. Additionally, designers can choose to install manual drawdown valves or flashboard risers (also called sliding weir plates) so that maintenance personnel can drain the wetland for maintenance purposes. If installed, drawdown valves should be secured so that only intended personnel can access them. Also, trash racks are recommended on the outlet structure to keep floating plants from clogging the outlet.

An ideal outlet structure should contain the following features:

- High-capacity weir box overflow;
- Low-capacity drawdown sized to draw down the temporary pool (shallow land zone) in 2-5 days; and
- Easy accessibility for operation and maintenance.

### Overflow Structure Maintenance Considerations

Stormwater wetland maintenance must be considered when designing outlet structures. Occasionally, wetlands may require complete drawdown. The structures in Figure 3 show the low-capacity drawdown orifice, the high-capacity overflow, and a manually operated valve for maintenance purposes. Alternatively, a flashboard riser can be used to draw water down for maintenance, as shown in Figure 4.

**Figure 3 Outlet Structures with Manual Drawdown Valve for Maintenance**

**Figure 4 Outlet Structure with Flashboard Riser for Maintenance** (Photos Courtesy of NC State Science House & BAE)

One method to help ensure that the drawdown orifice does not clog is to turn the orifice downward below the normal pool as shown in Figure 5. This prevents floating debris or vegetation from clogging the orifice. The site in Figure 5 has been drained for maintenance.

**Figure 5 Outlet Structure with Down-Turned Drawdown Orifice**

The overflow structure should be located near the edge of the wetland so that it can be accessed easily for maintenance, as shown in Figure 6.

**Figure 4 Outlet Structure Near Wetland Edge, Orifice Easily Accessible for Maintenance**

Overflow structures that are several feet into the wetland, as shown in Figure 7, are difficult to reach and likely will not be maintained.

**Figure 5 Outlet Structure Not Near Wetland Edge, Orifice *Not* Easily Accessible for Maintenance**

### Step 6: Select Plants

High pollutant-removal efficiencies in a stormwater wetland depend on a dense cover of emergent plant vegetation. Although various plant types differ in their abilities to remove pollutants from the water column, in general, the specific plant species do not appear to be as important for stormwater wetland functioning as plant growth survival and plant densities (Kadlex and Knight, 1996). In particular, species should be used that have high colonization and growth rates, can establish large areas that continue through the winter dormant season, have a high potential for pollutant removal, and are very robust in continuously or periodically flooded environments. Non-invasive species should be used. Native species are preferred.

Shrubs and wetland plants should be designed to minimize solar exposure of open water areas. A landscape plan should be prepared by a qualified design professional that outlines the methods to be used for maintaining wetland plant coverage.

A stormwater wetland facility consists of the area of the wetland, including bottom and side slopes, plus maintenance/access buffers around the wetland. Minimum elements of a stormwater wetland landscape plan include:

- Delineation of planting (pondscaping) zones;
- Selection of corresponding plant species;
- A minimum of ten (10) different species total, of which at least five (5) are emergent species, with no more than 30% of a single species;
- Buffers are recommended as centipede grass;
- Minimum plant quantities and sizes per 200 ft$^2$ of shallow water area: 50 herbaceous plants of at least 4-cubicinch container (equivalent to 2 ft on center minimum; 1.5 ft on center recommended)
- Minimum plant quantities and plant sizes per 200 ft$^2$ of shallow land area:

  50 herbaceous plants of at least 4-cubic inch container, OR

  8 shrubs of at least 1-gallon container (equivalent to 5 ft on center minimum; 3 ft on center recommended), OR

  1 tree of at least 3-gallon container and 40 grass-like herbaceous plants of at least 4-cubic inch container
- Source of plant materials (wetland seed mixes are not allowed);
- Planting layout;
- Sequence and timing for preparing wetland bed (including soil amendments, initial fertilization, and watering, as needed);
- Growing medium specifications (soil specifications); and
- Specification of supplementary plantings to replenish losses.

Soil bioengineering techniques, such as the use of fascines, stumps or logs, and coconut fiber rolls, can be used to create shallow land cells in areas of the stormwater wetland that may be subject to high flow velocities. The landscape plan should also provide elements that promote greater wildlife and waterfowl use within the wetland and buffers, as well as aesthetic considerations.

Five (5) or more species of emergent wetland plants should be selected in order to optimize treatment processes as well as to promote ecological mosquito control (i.e., attract a variety of predator insects for natural mosquito control). Use of trees and shrubs should be limited if mosquitoes are of concern, and these are best planted around the perimeter of the wetland. Cattails shall not be planted, as they can quickly take over and choke out other plants in the wetland, which will limit biodiversity and ultimately lead to mosquito infestation.

Plant recommendations are listed in Table 1. The listing of plant species is not exhaustive, and additional wetland plant species may be suitable that are not shown below. There are many excellent plant references in publication as well as recommendations from wetland scientists and landscape architects.

Table 1: Wetland Plant Recommendations

**DEEP POOL**

| **Botanical Name** | **Common Name** |
|---|---|
| **Floating Aquatic Plants** | |
| *Lemna* spp. | Duckweed |
| *Nelumbo lutea* | American lotus |
| *Nuphar lutea* ssp. *polysepala* | Rocky Mtn Pond-lily |
| *Nuphar lutea* ssp. *advena* | Yellow Pond-lily |
| **Submerged Aquatic Plants** | |
| *Eleocharis acicularis* | Needle spikerush |
| *Eleocharis quadrangulata* | Squarestem spikerush |
| *Elodea canadensis* | Canadian waterweed |
| *Elodea nuttallii* | Western waterweed |

**SHALLOW WATER**

| **Botanical Name** | **Common Name** |
|---|---|
| **Herbaceous Plants** | |
| *Acorus subcordatum* | Sweetflag |
| *Alisma subcordatum* | Water plantain |
| *Hydrolea quadrivalvis* | Waterpod |
| *Iris virginica* | Blue flag iris |
| *Juncus effusus var. pylaei or solutus* | Soft rush |
| *Ludwigia* spp. | Primrose willow |
| *Peltandra virginica* | Arrow arum |
| *Pontederia cordata* | Pickerelweed |
| *Sagittaria latifolia* | Duck Potato |
| *Sagittaria lancifolia* | Bulltongue |
| *Saururus cernuus* | Lizard’s tail |
| *Schoenoplectus tabernaemontani* | Soft stem bulrush |
| *Schoenoplectus americanus* | Three-square bulrush |
| *Schoenoplectus pungens var. pungens* | Common threesquare |
| *Scirpus cyperinus* | Woolgrass |
| *Zizaniopsis miliacea* | Giant cutgrass |

| SHALLOW LAND | |
|---|---|
| **Botanical Name** | **Common Name** |
| **Herbaceous Plants** | |
| *Asclepias incarnata* | Swamp Milkweed |
| *Carex tenera* | Quill sedge |
| *Chelone glabra* | White Turtlehead |
| *Eupatoriadelphus dubius* | Dwarf Joe Pye Weed |
| *Eupatoriadelphus fistulosus* | Joe Pye Weed |
| *Eupatoriadelphus maculatus* | Spotted trumpetweed |
| *Hibiscus coccineus* | Scarlet rose mallow |
| *Hibiscus laevis* | Halberdleaf rosemallow |
| *Kosteletzkya virginica* | Seashore Mallow |
| *Lobelia cardinalis* | Cardinal flower |
| *Lobelia elongata* | Longleaf lobelia |
| *Lobelia siphilitica* | Great blue Lobelia |
| *Rhynchospora colorata* | Starrush whitetop |
| *Saccharum baldwinii* | Narrow plumegrass |
| **Shrubs** | |
| *Aronia arbutifolia* | Red Chokeberry |
| *Cephalanthus occidentalis* | Common Buttonbush |
| *Clethra alnifolia* | Sweet pepperbush |
| *Cornus amomum* | Silky dogwood |
| *Cyrilla racemiflora* | TiTi |
| *Gordonia lasianthus* | Bushy St. Johnswort |
| *Hypericum densiflorum* | Possumhaw |
| *Ilex deciduas* | Inkberry |
| *Ilex glabra* | InkberryVirginia Sweetspire |
| *Itea virginica* | Swamp Rose |
| *Rosa palustris* | Creeping Blueberry |
| *Vaccinium crassifolium* | Possumhaw |
| *Viburnum nudum var. nudum* | Loblolly Bay |

## Design Variations

There are several variations of the wetland design. The designs are characterized by the volume of the wetland in deep pool, high marsh, and low marsh, and whether the design allows for detention of small storms above the wetland surface.

### Shallow Marsh

In the shallow marsh design, most of the wetland volume is in the relatively shallow high marsh or low marsh depths. The only deep portions of the shallow wetland design are the forebay at the inlet to the wetland and the micropool at the outlet. One disadvantage to this design is that, since the pool is very shallow, a large amount of land is typically needed to store the water quality volume (i.e., the volume of runoff to be treated in the wetland).

### Extended Detention Wetland

This design is the same as the shallow marsh, with additional storage above the surface of the marsh. Stormwater is temporarily ponded above the surface in the extended detention zone for 12 to 24 hours. This design can treat a greater volume of stormwater in a smaller space than the shallow wetland design. In the extended detention wetland option, plants that can tolerate wet and dry periods should be specified in the extended detention zone.

### Pond/Wetland System

The pond/wetland system combines the wet pond design (see *Wet Pond Practice*) with a shallow marsh. Stormwater runoff flows through the wet pond and into the shallow marsh. Like the extended detention wetland, this design requires less surface area than the shallow marsh because some of the volume of the practice is in the relatively deep (i.e., 6-8 feet) pond.

### Pocket Wetland

This design is very similar to the pocket pond (see *Wet Pond Practice*). In this design, the bottom of the wetland intersects the groundwater, which helps to maintain the permanent pool. Some evidence suggests that groundwater flows may reduce the overall effectiveness of stormwater-management practices (Brown and Schueler, 1997). This option may be used when there is not significant drainage area to maintain a permanent pool.

### Gravel-Based Wetlands

In this design, runoff flows through a rock filter with wetland plants at the surface. Pollutants are removed through biological activity on the surface of the rocks and pollutant uptake by the plants. This practice is fundamentally different from other wetland designs because, while most wetland designs behave like wet ponds with differences in grading and landscaping, gravel-based wetlands are more similar to filtering systems.

## Construction Considerations

The wetland must be stabilized within 14 days of construction. Consider construction sequencing so that vegetation can be planted and the wetland brought online within 14 days. Plants may need to be watered during this time if the device is not brought online the same day. Stabilization may be in the form of final vegetation plantings or a temporary means until the vegetation becomes established. A good temporary means of stabilization is a wet hydroseed mix. For rapid germination, scarify the soil to a half-inch prior to hydroseeding.

Inlet and outlet channels should be protected from scour that may occur during periods of high flow. Standard erosion-control measures should be used. *Volume 1 - Erosion and Sediment Control Manual* can provide information on erosion- and sediment-control techniques.

The stormwater wetland should be staked at the onset of the planting season. Water depths in the wetland should be measured to confirm the original planting zones. At this time, it may be necessary to modify the planting plan to reflect altered depths or the availability of wetland plant stock. Surveyed planting zones should be marked on an “as-built” or record design plan and located in the field using stakes or flags.

The wetland drain should be fully opened for no more than 3 days prior to the planting date (which should coincide with the delivery date for the wetland plant stock), to preserve soil moisture and workability.

The most common and reliable technique for establishing an emergent wetland community in a stormwater wetland is to transplant nursery stock obtained from local aquatic plant nurseries. The optimal period for transplanting extends from early April to mid-June so that the wetland plants will have a full growing season to build the root reserves needed to survive the winter. However, some species may be planted successfully in early fall. Contact your nursery well in advance of construction to ensure that they will have the desired species available.

Post-nursery care of wetland plants is very important in the interval between delivery of the plants and their subsequent installation because they are prone to desiccation. Stock should be frequently watered and shaded.

### Safety Considerations

The permanent pool of water presents an attractive play area to children and thus may create safety problems. Engineering design features that discourage child access are recommended. Trash racks and other debris-control structures should be sized to prevent entry by children. Other safety considerations include using fences around the spillway structure, embankment, and stormwater wetland slopes; using shallow safety benches around the stormwater wetland; and posting warning signs.

Fencing of stormwater wetlands is not generally aesthetically pleasing but may be required by the local review authority. A preferred method is to engineer the contours of the stormwater wetland to eliminate drop-offs and other safety hazards as discussed above. Riser openings must restrict unauthorized access. Endwalls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent falls.

## Common Problems

The landscape professional managing the wetland must understand the biological requirements of the plants and manage water levels appropriately to provide for their needs. For example, growing conditions are most critical during seed germination and early establishment. However, optimum conditions are not always required once the vegetated community becomes established.

Although wetland plants require water for growth and reproduction, they can be killed by drowning in excessively deep water. Usually, initial growth is best with transplanted plants in wet, well-aerated soil. Occasional inundation, followed by exposure of the majority of the vegetation to air, enables the plants to obtain oxygen and grow optimally. Conversely, frequent soil saturation is important for wetland plant survival.

If a minimum coverage of 70 percent is not achieved in the planted wetland zones after the second growing season, supplemental planting should be completed. Coverage of 90 to 95 percent is desirable.

Dramatic shifts can occur as plant succession proceeds. The plant community reflects management and can indicate problems or the results of improvements. For example, a requirement of submerged aquatic plants, such as pondweed (*Potamogeton* spp.), is light penetration into the water column. The disappearance of these plants may indicate inadequate water clarity. The appearance of invasive species or development of a monoculture is also a sign of a problem with the aquatic/soil/vegetative requirements. For instance, many invasive species can quickly spread and take over a wetland. If cattails become invasive, they can be removed by a licensed aquatic pesticide applicator by wiping aquatic glyphosate, a systemic herbicide, on the cattails.

Unlike maintenance requirements for wet or dry stormwater ponds, sediment should only be selectively removed from stormwater wetlands, primarily from the forebay. Sediment removal disturbs stable vegetation cover and disrupts flow paths through the wetland. The top few inches of sediment should be stockpiled so that it can be replaced over the surface of the wetland after the completion of sediment removal to re-establish the vegetative cover using its own seed bank. Accumulated sediment should be removed from around inlet and outlet structures.

## Maintenance

- Immediately following construction of the stormwater wetland, bi-weekly inspections will be conducted and wetland plants will be watered bi-weekly until vegetation becomes established (commonly six weeks).
- No portion of the stormwater wetland will be fertilized after the first initial fertilization that is required to establish the wetland plants.
- Stable groundcover will be maintained in the drainage area to reduce the sediment load to the wetland.
- Once a year, a dam safety expert should inspect the embankment.

# Dry Detention Pond

## Practice Description

As the name of this BMP implies, these basins are typically dry between storm events. A low-flow outlet slowly releases water retained over a period of days. This BMP can be applied in residential, industrial, and commercial developments where sufficient space is available. The primary purpose of dry extended detention basins is to attenuate and delay stormwater runoff peaks. They are appropriate where water quality issues are secondary to managing peak runoff, since the overall pollutant removal efficiency of dry extended detention basins is low. Dry extended detention basins are not intended as infiltration or groundwater recharge measures

## Planning Considerations

Dry detention ponds have traditionally been one of the most widely used stormwater best management practices. In some instances, these ponds may be the most appropriate best management practice. However, they should not be used as a “one size fits all: solution. If pollutant removal efficiency is an important consideration, dry detention ponds may not be the most appropriate choice. Dry detention ponds require a large amount of space to build. In many instances, smaller sized best management practices are more appropriate alternatives (see *Grassed Swales, Infiltration Basin, Infiltration Trench, Pervious Asphalt Pavement*, *Bioretention (Rain Gardens), Permeable Interlocking Concrete Paving,* or *Green Roofs*).

# Design Criteria

### Converting Sediment and Erosion Control Devices

Sediment basins that are used during construction can be converted into dry extended detention basins after the construction is completed. If used during construction as a sediment basin, the basin must be completely cleaned out, graded, and vegetated within 14 days of completion of construction.

# Siting Considerations

Designers need to ensure that the dry detention pond is feasible at the site in question. This section provides basic guidelines for siting dry detention ponds.

### Drainage Area

Dry extended detention basins can be utilized on very large sites, but often reach limitations around 25 acres or more. The most common limitation is the bottom of the basin approaching groundwater.

### Slope

Dry detention ponds can be used on sites with slopes up to about 15 percent. The local slope needs to be relatively flat, however, to maintain reasonably flat side slopes in the practice. There is no minimum slope requirement, but there does need to be enough elevation drop from the pond inlet to the pond outlet to ensure that flow can move through the system.

### Soils/Topography

Dry detention ponds can be used with almost all soils and geology, with minor design adjustments for regions of karst topography or in rapidly percolating soils such as sand. In these areas, extended detention ponds should be designed with an impermeable liner to prevent groundwater contamination or sinkhole formation.

### Ground Water

Except for the case of hot spot runoff, the only consideration regarding groundwater is that the base of the extended detention facility should not intersect the groundwater table. A permanently wet bottom may become a mosquito breeding ground. Research in southwest Florida (Santana et al., 1994) demonstrated that intermittently flooded systems, such as dry extended detention ponds, produced more mosquitoes than other pond systems, particularly when the facilities remained wet for more than 3 days following heavy rainfall.

# Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. Some features, however, should be incorporated into most dry extended detention pond designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

## Pretreatment

A forebay is highly recommended at the inlet of a dry extended detention basin to trap incoming sediment if the design flow to the facility is over 10 acre-inches. A forebay is recommended on all other dry detention basins. With heavy, coarse sediment confined to the forebay area, maintenance is made simpler and less costly and the life of the BMP is extended.

To prevent resuspension of trapped sediment and scour during high flows, the energy of the influent flow must be controlled. This can be in the form of a forebay as mentioned above, a plunge pool, riprap, or other energy-dissipating and erosion-control measures.

## Treatment

Treatment design features help enhance the ability of a stormwater management practice to remove pollutants. Designing dry ponds with a high length-to-width ratio (i.e., at least 1.5:1) and incorporating other design features to maximize the flow path effectively increases the detention time in the system by eliminating the potential of flow to short-circuit the pond. Designing ponds with relatively flat side slopes can also help to lengthen the effective flow path. Finally, the pond should be sized to detain the volume of runoff to be treated for between 12 and 48 hours.

## Length, Width, Depth and Geometry

The volume of a dry extended detention basin is driven exclusively by the volume of stormwater that is required to be captured. Once that volume is calculated, the dimensional aspect of the basin is mostly site driven. Below are some dimensional and layout requirements:

- The maximum depth shall be 10 feet.
- A minimum of 1 foot of freeboard shall be provided between the design flow pool elevation and the emergency overflow invert.

- The minimum flow length-to-width ratio shall be 1.5:1, but 3:1 is recommended. The basin width should preferably expand as it approaches the outlet.

- Side slopes of the basin shall be no steeper than 3H:1V if stabilized by vegetation.

- In addition to detention volume, design must provide for sediment storage equal to 25 percent of detention volume. If it is known that the upstream drainage basin will contribute high sediment loads (e.g. construction) over several years, then additional sediment storage should be provided.

By causing turbulence and eddies in the flow, flow short-circuiting can interfere with the function of the basin outlet system and should therefore be minimized. The most direct way of minimizing short-circuiting is to maximize the distance between the riser and the inlet. Larger length-to-width ratios should be used if sedimentation of particulates during low flows is desirable. Irregularly shaped basins appear more natural. If a relatively long, narrow facility is not suitable at a given site, baffles constructed from gabions or other materials can be placed in the basin to lengthen the flowpath.

A sinuous low-flow channel should be constructed through the basin to transport dry-weather flows and minor storm flows. Preferably, the channel would be grass lined and sloped at approximately 2 percent to promote drainage of the basin between storms. The entire bottom of the basin should drain toward the low-flow channel.

### Conveyance

Conveyance of stormwater runoff into and through the dry pond is a critical component. Stormwater should be conveyed to and from dry ponds safely in a manner that minimizes erosion potential. The outfall of pond systems should always be stabilized to prevent scour. To convey low flows through the system, designers should provide a pilot channel. A pilot channel is a surface channel that should be used to convey low flows through the pond. In addition, an emergency spillway should be provided to safely convey large flood events. To help mitigate the warming of water at the outlet channel, designers should provide shade around the channel at the pond outlet.

### Outlet Design

In addition to meeting specific hydraulic requirements for runoff detention and peak attenuation, outlets also must be functionally simple and easy to maintain. Below are design requirements and guidelines for dry extended detention basin outlets:

- Basin design should include a small permanent pool near the outlet orifice to reduce clogging and keep floating debris away from the outlet.

- Basin design must include a drain that will completely empty the basin for clean-out.

- Durable materials such as reinforced concrete or plastic are preferable to corrugated metal in most instances.
- The riser should be placed in or at the face of the embankment to make maintenance easier and prevent flotation problems.
- Erosion protection measures should be used at the basin discharge point.
- To prevent piping and internal erosion problems around the spillway/outlet conduit through an embankment system, a filter diaphragm and drainage system is recommended.

### Maintenance Reduction

Regular maintenance activities are needed to maintain the function of stormwater practices. In addition, some design features can be incorporated to ease the maintenance burden of each practice. In dry detention ponds, a “micropool” at the outlet can prevent resuspension of sediment and outlet clogging. A good design includes maintenance access to the forebay and micropool.

Another design feature that can reduce maintenance needs is a non-clogging outlet. Typical examples include a reverse-slope pipe or a weir outlet with a trash rack. A reverse slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and determines the water elevation of the micropool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris.

### Landscaping

When choosing vegetation for a dry extended detention basin, consideration must be given to the wildflowers or grasses specified because of the frequent inundations, warm and cold seasons, as well as salt and oil loading. Additionally, the plants should not be fertilized except for a one-time application after seeding. Mowing should be minimal. It has been found that a wet meadow mix or Bermuda grass typically performs well in those locations with the climate able to support it.

The dry extended detention basin must be stabilized within 14 days after the end of construction. The stabilization might be the final vegetation or a temporary stabilization measure until the vegetation becomes established.

## Design Variations

### Tank Storage

Another variation of the dry detention pond design is the use of tank storage. In these designs, stormwater runoff is conveyed to large storage tanks or vaults underground. This practice is most often used in the ultra-urban environment on small sites where no other opportunity is available to provide flood control. Tank storage is provided on small areas because underground storage for a large drainage area would generally be costly. Because the drainage area contributing to tank storage is typically small, the outlet diameter needed to reduce the flow from very small storms would very small. A very small outlet diameter, along with the underground location of the tanks, creates the potential for debris being caught in the outlet and resulting maintenance problems. Since it is necessary to control small runoff events (such as the runoff from a 1-inch storm) to improve water quality, it is generally infeasible to use tank storage for water quality and generally impractical to use it to protect stream channels.

## Common Problems

Although dry detention ponds are widely applicable, they have some limitations that might make other stormwater management options preferable:

- Dry detention ponds have only moderate pollutant removal when compared to other structural stormwater practices, and they are ineffective at removing soluble pollutants.
- Dry extended detention ponds may become a nuisance due to mosquito breeding if improperly maintained or if shallow pools of water form for more than 7 days.
- Although wet ponds can increase property values, dry ponds can actually detract from the value of a home.
- Dry detention ponds on their own only provide peak flow reduction and do little to control overall runoff volume, which could result in adverse downstream impacts.

## Maintenance

– The drainage area will be managed to reduce the sediment load to the dry extended detention basin.

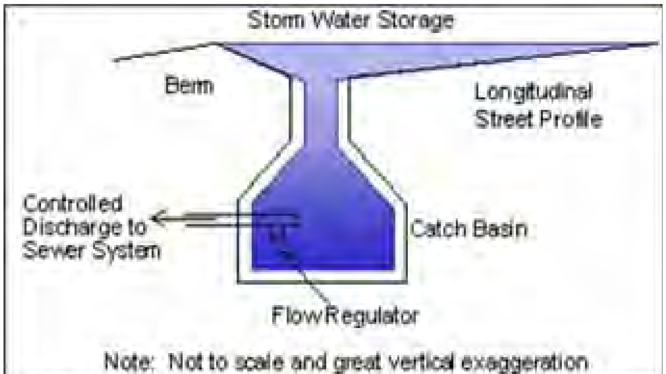
– Immediately after the dry extended detention basin is established, the vegetation will be watered twice weekly, if needed, until the plants become established (commonly six weeks).

– No portion of the dry extended detention pond will be fertilized after the first initial fertilization that is required to establish the vegetation.

– The vegetation in and around the basin should be maintained at a height of approximately six inches.

– Once a year, a dam safety expert will inspect the embankment.

# In-Line Storage




**Catch basins can be equipped with flow restrictors to temporarily detain storm water in the conveyance system**

Source: EPA

## Practice Description

In-line storage refers to a number of practices designed to use the storage within the storm drain system to detain flows. While these practices can reduce storm peak flows, they are unable to improve water quality and offer limited protection of downstream channels. Hence, the U.S. Environmental Protection Agency does not recommend using these practices in many circumstances. Storage is achieved by placing devices in the storm drain system to restrict the rate of flow. Devices can slow the rate of flow by backing up flow, as in the case of a dam or weir, or through the use of vortex valves (devices that reduce flow rates by creating a helical flow path in the structure). A description of various flow regulators is included in Urbonas and Stahre (1990).

## Planning Considerations

In-line storage practices serve a similar purpose as traditional detention basins (see *Dry Detention Ponds Practice*). These practices can act as surrogates for aboveground storage when little space is available for aboveground storage facilities.

## Design Criteria

Flow regulators cannot be applied to all storm drain systems. In older cities, the storm drain pipes may not be oversized, and detaining stormwater within them would cause upstream flooding. Another important issue in siting these practices is the slope of the pipes in the system. In areas with very flat slopes, restricting flow within the system is likely to cause upstream flooding because introducing a regulator into the system will cause flows to back up a long distance before the regulator. In steep pipes, on the other hand, a storage flow regulator cannot utilize much of the storage available in the storm drain system.

## Common Problems

In-line storage practices only control stormwater quantity and are not efficient at improving runoff water quality.

Without proper design, these practices often cause upstream flooding.

## Maintenance

Flow regulators require very little maintenance because they are designed to be "self-cleaning," much like the storm drain system. In some cases, flow regulators may be modified based on downstream flows, new connections to the storm drain, or the application of other flow regulators within the system. For some designs, such as check dams, regulations will require only moderate construction in order to modify the structure's design.

# Wet Pond

## Practice Description

Wet ponds (a.k.a. stormwater ponds, wet retention ponds, wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season). In wet detention basins, a permanent pool of standing water is maintained by the riser—the elevated outlet of the wet detention basin. Water in the permanent pool mixes with and dilutes the initial runoff from storm events. Wet detention basins fill with stormwater and release most of the mixed flow over a period of a few days, slowly returning the basin to its normal depth.

Runoff generated during the early phases of a storm usually has the highest concentrations of sediment and dissolved pollutants. Because a wet detention basin dilutes and settles pollutants in the initial runoff, the concentration of pollutants in the runoff released downstream is reduced. Following storm events, pollutants are removed from water retained in the wet detention basin. Two mechanisms that remove pollutants in wet detention basins include settling of suspended particulates and biological uptake, or consumption of pollutants by plants, algae, and bacteria in the water. However, if the basin is not adequately maintained (e.g., by periodic excavation of the captured sediment), storm flows may re-suspend sediments and deliver them to the stream.

## Planning Considerations

Wet detention basins are applicable in residential, industrial, and commercial developments where enough space is available. Wet detention basins are sized and configured to provide significant removal of pollutants from the incoming stormwater runoff. The permanent pool of water is designed for a target total suspended solids removal efficiency according to the size and imperviousness of the contributing watershed. Above this permanent pool of water, wet detention basins are also designed to hold the runoff volume required by the stormwater regulations, and to release it over a period of 2 to 5 days. As a result, most of the suspended sediment and pollutants attached to the sediment settle out of the water. In addition, water is slowly released so that downstream erosion from smaller storms is lessened.

## Design Criteria

### Converting Erosion- and Sediment-Control Devices

Wet detention basins are typically part of the initial site clearing and grading activities and are often used as sediment basins during construction of the upstream development. Volume 1 contains design requirements for sediment basins required during construction. A sediment basin typically does not include all the engineering features of a wet detention basin, and the design engineer must ensure that the wet detention basin includes all the features identified in this section, including the full sizing as a wet detention basin. If the wet detention basin is used as a sediment trap during construction, all sediment deposited during construction must be removed, erosion features must be repaired, and the vegetated shelf must be restored, before operation as a stormwater BMP begins.

#### *Siting Considerations*

Because large storage volumes are needed to achieve extended detention times, wet detention basins require larger land areas than many other BMPs. Wet detention basins may not be suitable for projects with very limited available land. Permanent retaining walls may be used to obtain the required design volumes while reducing the footprint that would otherwise be required for earthen construction. Retaining walls utilized to contain the permanent pool must not reduce the required 10′ width of the vegetated shelf, and must not extend to a top elevation above the lowest point of the vegetated shelf. Retaining walls utilized to contain the temporary pool must not reduce the required 10′ width of the vegetated shelf, and must not be in contact with the stormwater stored up to the temporary pool elevation. Two retaining walls may be used, as shown in Figure 1. Or, the design may be altered to contain only one of the two shown.

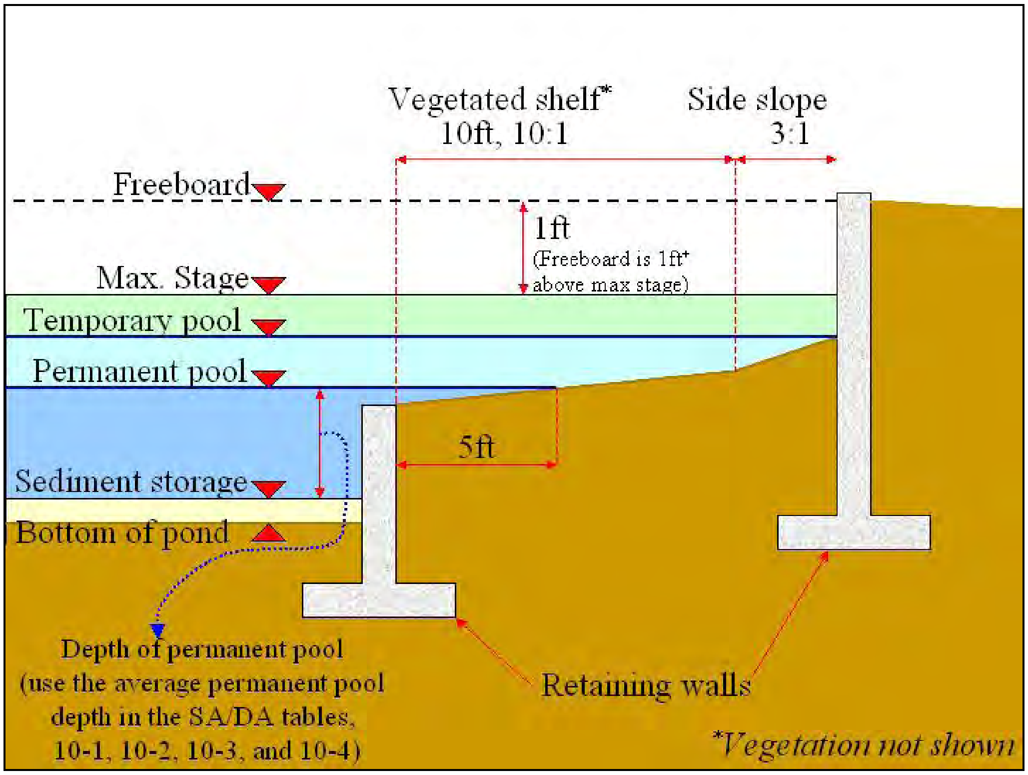



Figure 1  Alternative Wet Pond Design: Retaining Wall Option

### Drainage Area

Wet ponds need sufficient drainage area to maintain the permanent pool. In humid regions, this is typically about 25 acres, but a greater area may be needed in regions with less rainfall. BMPs that focus on source control, such as bioretention, should be considered for smaller drainage areas.

### Slope

Wet ponds can be used on sites with an upstream slope up to about 15 percent. The local slope should be relatively shallow, however. Although there is no minimum slope requirement, there does need to be enough elevation drop from the pond inlet to the pond outlet to ensure that water can flow through the system.

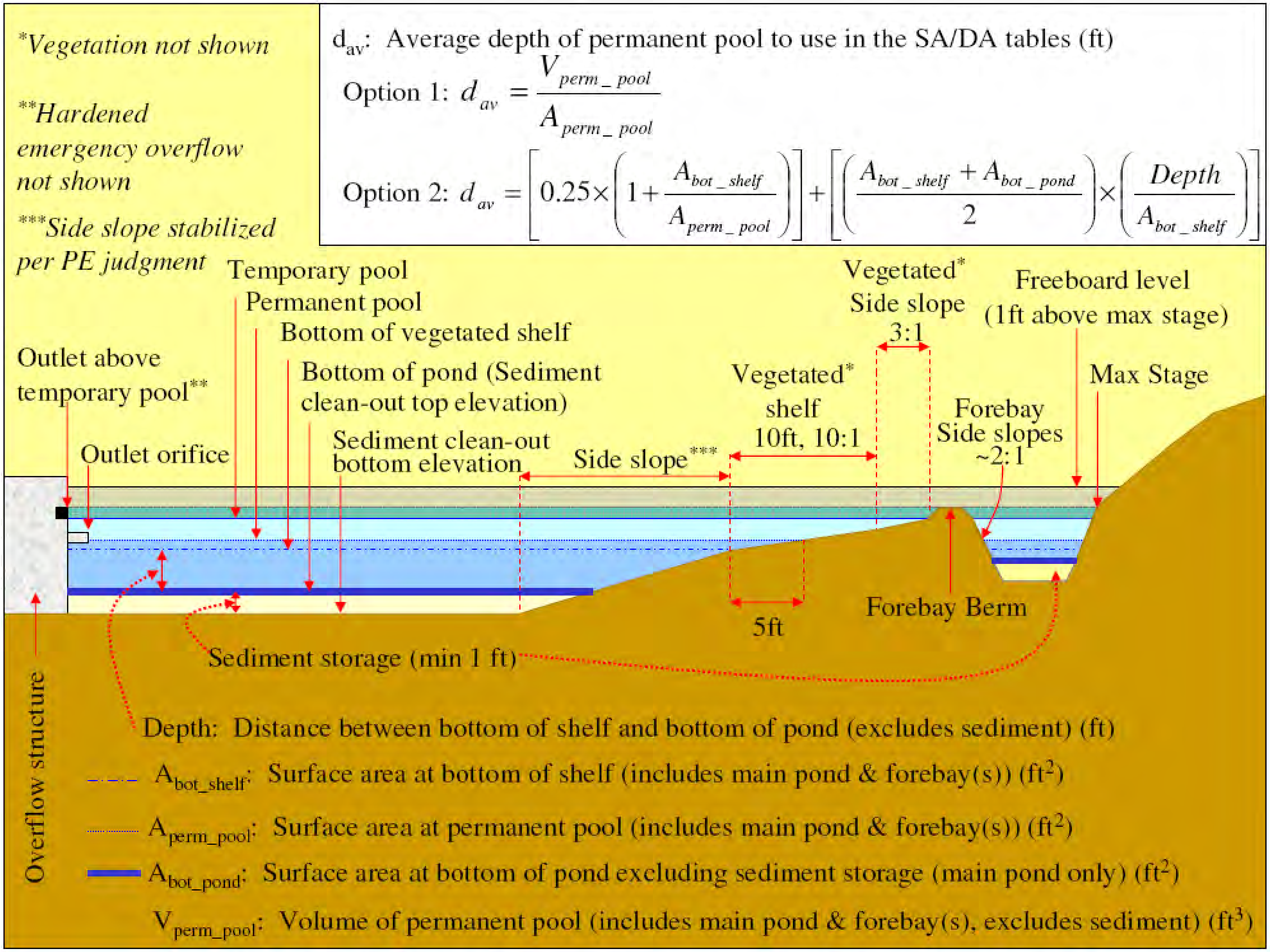



Figure 2  Basic Wet Detention Basin Elements: Cross Section

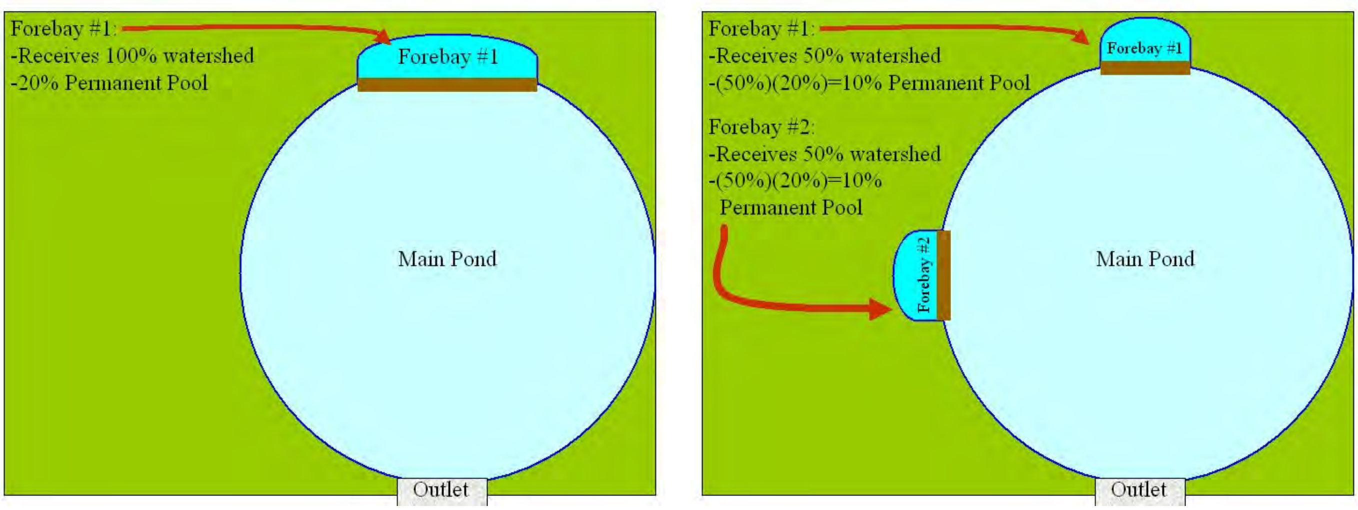
## Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most wet pond designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

### Pretreatment

Forebays are highly recommended on all inlets to a wet detention basin. A properly engineered forebay can concentrate large particle-size sediment for easier removal, and can dissipate the incoming flow energy prior to the stormwater entering the main part of the BMP. The dissipation of incoming flow energy reduces re-suspension of settled material in the main pool, and it reduces the likelihood of erosion features within the BMP. Also, the forebay itself should be configured for energy dissipation within the forebay to avoid re-suspension of large-particle settled material previously captured in the forebay. One of several engineering means of energy dissipation is to have the inlet pipe submerged below the permanent forebay pool level, provided that the inlet placement does not serve to re-suspend previously captured sediment.

It is recommended that the design volume for the forebay be approximately 20% of the total calculated permanent pool volume. The main pool of the permanent pool would then account for approximately 80% of the design volume. If the pond has more than one forebay, the total volume of the forebays should equal 20% of the permanent pool volume. In this case, each forebay should be sized as in Figures 3–5.




Figures 3–4 Forebay Sizing Examples (continued)

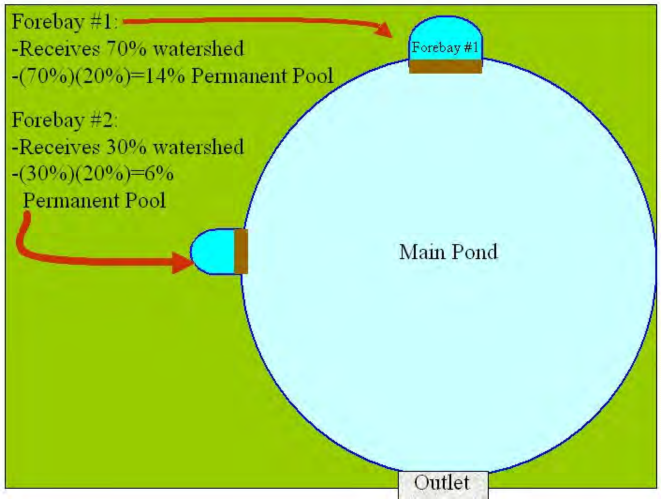



Figure 5 Forebay Sizing Examples (concluded)

## Treatment

Treatment design features help enhance the ability of a stormwater management practice to remove pollutants. The purpose of most of these features is to increase the amount of time that stormwater remains in the pond.

One technique of increasing the pollutant removal of a pond is to increase the volume of the permanent pool. Typically, ponds are sized to be equal to the water quality volume (i.e., the volume of water treated for pollutant removal). Designers may consider using a larger volume to meet specific watershed objectives, such as phosphorus removal in a lake system. Regardless of the pool size, designers need to conduct a water balance analysis to ensure that sufficient inflow is available to maintain the permanent pool.

Other design features do not increase the volume of a pond, but can increase the amount of time stormwater remains in the practice and eliminate short-circuiting. Ponds should always be designed with a length-to-width ratio of at least 1.5:1. In addition, the design should incorporate features to lengthen the flow path through the pond, such as underwater berms designed to create a longer route through the pond. Combining these two measures helps ensure that the entire pond volume is used to treat stormwater. Another feature that can improve treatment is to use multiple ponds in series as part of a "treatment train" approach to pollutant removal. This redundant treatment can also help slow the rate of flow through the system. Additionally, a vegetated buffer with shrubs or trees around the pond area should provide shading and consequent cooling of the pond water.

If designers of wet ponds are anticipating ponds that stratify in the summer, they might want to consider installing a fountain or other mixing mechanism. This will ensure that the full water column remains oxic.

## Conveyance

### Length, Width (Area), Depth, Geometry

Depth is an important engineering design criterion because most of the pollutants are removed through settling. Very shallow basins may develop currents that can re-suspend materials; on the other hand, very deep wet detention basins can become thermally stratified and/or anoxic and release pollutants back into the water.

The engineering design of a wet detention basin must include a 10-foot-wide (minimum) vegetated shelf around the full perimeter of the basin. The inside edge of the shelf shall be no deeper than 6″ below the permanent pool level, and the outside edge shall be 6″ above the permanent pool level. For a 10′ wide shelf, the resulting slope is 10:1. With half the required shelf below the water (maximum depth of 6 inches), and half the required shelf above the water, the vegetated shelf will provide a location for a diverse population of emergent wetland vegetation that enhances biological pollutant removal, provides a habitat for wildlife, protects the shoreline from erosion, and improves sediment trap efficiency. A 10′ wide shelf also provides a safety feature prior to the deeper permanent pool.

Short-circuiting of the stormwater must be prevented. The most direct way of minimizing short-circuiting is to maximize the length of the flow path between the inlet and the outlet: basins with long and narrow shapes can maximize the length of the flow path. Long and narrow but irregularly shaped wet detention basins may appear more natural and therefore may have increased aesthetic value. If local site conditions prohibit a relatively long, narrow facility, baffles may be placed in the wet detention basin to lengthen the stormwater flow path as much as possible. Baffles must extend to the temporary pool elevation or higher. A minimum length-to-width ratio of 1.5:1 is required, but a flow path of at least 3:1 is recommended. Basin shape should minimize dead storage areas and, where possible, the width should expand as it approaches the outlet.

Although larger wet detention basins typically remove more pollutants, a threshold size seems to exist above which further improvement of water quality by sedimentation is negligible. The permanent pool volume within a wet detention basin is calculated as the total volume beneath the permanent pool water level, and above the sediment storage volume, including any such volume within the forebay.

### Outlet Design

The outlet device shall be designed to release the temporary pool volume (minimum required treatment volume as calculated by the Simple Method) over a period of 48 to 120 hours (2 to 5 days). Longer detention times typically do not improve settling efficiency significantly, and the temporary pool volume must be available for the next storm. In addition, prolonged periods of inundation can adversely affect the wetland vegetation growing on the vegetated shelf.

In addition to being designed to achieve the 2- to 5-day drawdown period, outlets also must be functionally simple and easy to maintain. One possible configuration option of the outlet piping that simplifies maintenance and reduces the potential for obstruction is the submerged orifice arrangement shown in Figure 6.

Durable materials, such as reinforced concrete, are preferable to corrugated metal in most instances. The riser should be placed in or at the face of the embankment. By placing the riser close to the embankment, maintenance access is facilitated and flotation forces are reduced. The design engineer must present flotation force calculations for any outlet design subject to flotation forces.

Emergency overflow spillways must be designed with hardened materials at the points where extreme conditions might compromise the integrity of the structure.

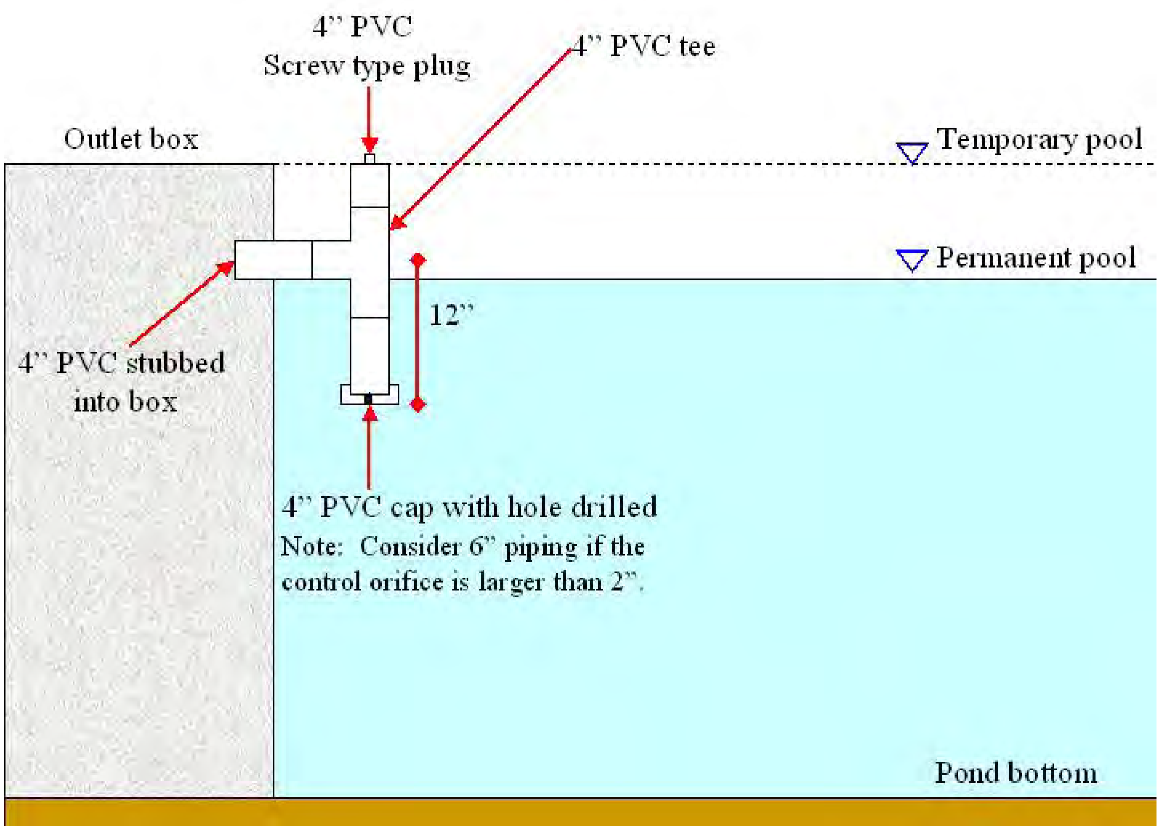



**Figure 6**

Typical Submerged Orifice Outlet Configuration

## Maintenance Reduction

In addition to regular maintenance activities needed to maintain the function of stormwater practices, some design features can be incorporated to ease the maintenance burden of each practice. In wet ponds, maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

One potential maintenance concern in wet ponds is clogging of the outlet. Ponds should be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack. A reverse-slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris. Another general rule is that no orifice should be less than 3 inches in diameter. (Smaller orifices are more susceptible to clogging.)

Design features are also incorporated to ease maintenance of both the forebay and the main pool of ponds. Ponds should be designed with maintenance access to the forebay to ease this relatively routine (5.7 year) maintenance activity. In addition, ponds should generally have a pond drain to draw down the pond for the more infrequent dredging of the main cell of the pond.

### Fountains in the Wet Pond

Fountains are optional, decorative wet pond amenities. If they are included, they shall be designed as follows:

1. Ponds smaller than 30,000 $ft^3$ cannot have a fountain.
2. The fountain must draw its water from less than 2′ below the permanent pool surface.
3. Separated units (where the nozzle, pump and intake are connected by tubing) may be used only if they draw water from the surface in the deepest part of the pond.
4. The falling water from the fountain must be centered in the pond, away from the shoreline.
5. The maximum horsepower for the fountain’s pump is based on the permanent pool volume, as described in Table 1. As an example, if the pond’s volume is 350,000 cubic feet, the maximum pump horsepower for the fountain is 1.

**Table 1**
Fountain Pump Power Requirements

| **Minimum Pond Volume ($ft^3$)** | **Max Pump HP** |
|---|---|
| 30,000 | 1/8 |
| 40,000 | 1/6 |
| 60,000 | 1/4 |
| 80,000 | 1/3 |
| 125,000 | 1/2 |
| 175,000 | 3/4 |
| 250,000 | 1 |
| 450,000 | 2 |
| 675,000 | 3 |

### Landscaping

Landscaping of wet ponds can make them an asset to a community and can also enhance the pollutant removal of the practice. A vegetated buffer should be preserved around the pond to protect the banks from erosion and provide some pollutant removal before runoff enters the pond by overland flow. In addition, ponds should incorporate an aquatic bench (i.e., a shallow shelf with wetland plants) around the edge of the pond. This feature may provide some pollutant uptake, and it also helps to stabilize the soil at the edge of the pond and enhance habitat and aesthetic value.

## Construction Considerations

Even moderate rainfall events during the construction of a wet detention basin can cause extensive damage to it. Protective measures should be employed both in the contributing drainage area, and at the wet detention basin itself. Temporary drainage or erosion control measures should be used to reduce the potential for damage to the wet detention basin before the site is stabilized. The control measures may include stabilizing the surface with erosion mats, sediment traps, and diversions. Vegetative cover and the emergency spillway also should be completed as quickly as possible during construction.

The designer should address the potential for bedding erosion and catastrophic failure of any buried outlet conduit. A filter diaphragm and drain system should be provided along the barrel of the principal spillway to prevent piping. There has been an evolution in standard practice, and the accumulated evidence suggests that, in most circumstances, filter diaphragms are much superior to anti-seep collars in preventing piping. Filter diaphragms are preferred over the older design anti-seep collar.

If reinforced concrete pipe is used for the principal spillway, “O-ring” gaskets (ASTM C361) should be used to create watertight joints and should be inspected during installation.

### Safety Considerations

The permanent pool of water presents an attractive play area to children and thus may create safety problems. Engineering design features that discourage child access are recommended. Trash racks and other debris-control structures should be sized to prevent entry by children. Other safety considerations include using fences around the spillway structure, embankment, and wet detention basin slopes; using shallow safety benches around the wet detention basin; and posting warning signs.

Fencing of wet detention basins is not generally aesthetically pleasing but may be required by the local review authority. A preferred method is to engineer the contours of the wet detention basin to eliminate drop-offs and other safety hazards as discussed above. Riser openings must not permit unauthorized access. End walls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent falls.

### Design Variations

There are several variations of the wet pond design. Some of these design alternatives are intended to make the practice adaptable to various sites and to account for regional constraints and opportunities.

#### Wet Extended Detention Pond

The wet extended detention pond combines the treatment concepts of the dry extended detention pond and the wet pond. In this design, the water quality volume is split between the permanent pool and detention storage provided above the permanent pool. During storm events, water is detained above the permanent pool and released over 12 to 48 hours. This design has similar pollutant removal to a traditional wet pond and consumes less space. Wet extended detention ponds should be designed to maintain at least half the treatment volume of the permanent pool. In addition, designers need to carefully select vegetation to be planted in the extended detention zone to ensure that the selected vegetation can withstand both wet and dry periods.

#### Water Reuse Pond

Some designers have used wet ponds to act as a water source, usually for irrigation. In this case, the water balance should account for the water that will be taken from the pond. One study conducted in Florida estimated that a water reuse pond could provide irrigation for a 100-acre golf course at about one-seventh the cost of the market rate of the equivalent amount of water ($40,000 versus $300,000).

## Common Problems

Limitations of wet ponds include:

- If improperly located, wet pond construction may cause loss of wetlands or forest.
- Wet ponds are often inappropriate in dense urban areas because each pond is generally quite large.
- Wet ponds may pose safety hazards.

## Maintenance

– Immediately after the wet detention basin is established, the plants on the vegetated shelf and perimeter of the basin should be watered twice weekly, if needed, until the plants become established (commonly six weeks).

– No portion of the wet detention pond should be fertilized after the first initial fertilization that is required to establish the plants on the vegetated shelf.

– Stable groundcover should be maintained in the drainage area to reduce the sediment load to the wet detention basin.

- If the basin must be drained for an emergency or to perform maintenance, the flushing of sediment through the emergency drain should be minimized to the maximum extent practical.

- Once a year, a dam safety expert should inspect the embankment.

## Additional Recommended Design Criteria, Specifications and Methodologies

The following criteria, specifications, and methodologies are recommended for stormwater management systems that are not specified by applicable regulatory requirements of federal, state or local jurisdictions.

**Wet Detention Systems:** These systems collect and temporarily store stormwater in a permanently wet impoundment in such a manner as to provide for treatment through physical, chemical, and biological processes with subsequent gradual release of the stormwater. These systems should be designed to meet the following requirements:

1. Required volume: First 0.5 inch of runoff or 1.5 inches of runoff from impervious area.

2. Return time: Outfall structure must discharge one half (½) volume of stormwater within 48 to 72 hours. No more than one half (½) the volume will be discharged within 48 hours.

3. Permanent pool: Provide average residence time at least 14 days during wet season

4. Littoral zone design:

   a. Sloped (4:1 or flatter) to a depth of at least 2 feet below control elevation; approximately 30 percent of the wet detention system surface area should be littoral zone (ratio of vegetated littoral zone to surface area of the pond at the control elevation).
   b. The treatment volume should not cause pond level to rise more than 18 inches above the control elevation, unless the littoral zone vegetation can survive at greater depths.
   c. Eighty percent coverage of the littoral zone vegetation should be established within the first 24 months. Portions of the littoral zone may be established by placement of wetland topsoils (at least a four-inch depth) containing a seed source of desirable native plants. To utilize this alternative, the littoral zone must be stabilized by mulching or other means.

5. A forebay should be established at the pond inflow points to capture larger sediment particles and be 4 to 6 feet deep. The forebay volume should equal about 20% of the total basin volume. Multiple inlets may require additional volume. Direct maintenance access should be a minimum of 15 feet wide, with a maximum slope of 5:1.

6. Mean depth of the permanent pool should be between 2 and 8 feet. The maximum depth should not exceed 12 feet below the invert of the outlet device, unless the deeper depths will not inhibit physical, chemical, and biological treatment processes or cause re-suspension of pollutants into the water column due to anaerobic conditions in the water column.

7. Flow path through pond should have an average length-to-width ratio of at least 2:1. The alignment and location of inlets and outlets should maximize flow paths in the pond. If short flow paths are unavoidable, the effective flow path should be increased by adding diversion barriers such as islands, peninsulas, or baffles to the pond. Inlet structures should be designed to dissipate the energy of water entering the pond.

8. Outlet devices incorporating dimensions smaller than three inches minimum width or less than 20 degrees for “v” notches should include a device to eliminate clogging. Examples include baffles, grates, and pipe elbows.

9. Outlet structure invert elevations should be at or above the estimated post-development normal groundwater table elevation. If the proposed structure is set below this elevation, groundwater inflow must be considered in the drawdown calculations, calculation of average residence time, estimated normal water level in the pond, and pollution removal efficiency of the system.

10. Permanent maintenance easements or other acceptable legal instruments to allow for access to and maintenance of the system (including the pond, littoral zone, inlets, and outlet) should be established.

**Dry Retention Systems:** These systems are designed to collect and temporarily store stormwater in a normally dry basin with subsequent gradual release of the stormwater. Dry detention is recommended as an off-line system, but if the design calls for an in-line system, additional volume may be required. Additional volume may be required for on-line systems. These systems should be incorporated as a best management practice in a treatment train approach, which includes other best management practices including, but not limited to, grassed swales, level spreaders, filter strips, buffer zones, bioretention, and skip curbs—all with water flow lengths less than 300 feet. Dry retention systems are not recommended for use in areas that require piped water conveyance systems. These systems should be designed to meet the following requirements:

1. Required volume: first 1.0 inch of runoff or 2.5 inches from impervious areas, whichever is greater.

2. Return Time: Discharge one-half the appropriate treatment volume of stormwater specified above between 24-30 hours following a storm event.

3. Discharge structures should include a device to prevent the discharge of accumulated sediment, minimize exit velocities, and prevent clogging. A perforated riser enclosed in a gravel jacket and perforated pipes enclosed in sand or gravel is a good example.

4. Contain areas of standing water for no more than 3 days following a storm event.

5. Stabilize with permanent native vegetative cover.

6. Average flow path through the basin should have a length-to-width ratio of at least 3:1. The alignment and location of inlets and outlets should be designed to maximize flow paths in the basin. If short flow paths are unavoidable, the effective flow path should be increased by adding diversion barriers such as baffles.

7. Inlet structures should be designed to dissipate the energy of water entering the basin.

8. A maintenance schedule is recommended for removal of sediment and debris on at least a bi-monthly basis, as well as mowing and removal of grass clippings.

9. Basin floor should be level or uniformly sloped (1-2% maximum) toward the outfall structure.

10. Basin floor should be at least three feet above the seasonal high groundwater table elevation. Sumps may be placed up to one foot below the control elevation.

11. Permanent maintenance easements or other acceptable legal instruments should be in place to allow for access to and maintenance of the system. The easement or other acceptable instrument should cover the entire stormwater system.

**<u>Constructed Wetland Systems</u>:** Wetland systems collect and temporarily store stormwater in a permanently wet impoundment and provide treatment through physical, chemical, and biological processes. These systems should be designed to meet the following requirements.

1. Required volume: First 1.0 inch of runoff or 2.5 inches of runoff from impervious area.

2. Inflow of water must be greater than infiltration.

3. Designed for an extended detention time of 24 hours for the 1-year storm event.

4. Protection against blockage should be installed around outlets vulnerable to blockage from plant material or other debris that will enter the basin with stormwater runoff. Reverse slope pipes are recommended.

5. Surface area of the wetland should account for a minimum 3% of the area of the watershed draining into it.

6. The length-to-width ratio should be at least 3 to 1.

7. Deeper area of the wetland should include the outlet structure so that the outflow from the basin is not impeded by sediment buildup.

8. A forebay should be established at the pond inflow points to capture larger sediment particles and be 4 to 6 feet deep. The forebay volume should equal about 20% of the total basin volume. Multiple inlets may require additional forebay volume. Direct maintenance access should be a minimum of 15 feet wide, with a maximum slope of 5:1.

9. In cases where water velocities exceed 0.5 ft/s, energy dissipation devices should be installed.

10. Pre- and post-grading pondscaping design should be used to create both horizontal and vertical diversity and habitat.

11. Approximately 30 to 50 percent of the shoulder area (12 inches or less) of the basin should be planted with native wetland vegetation.

12. A 25-foot buffer, for all but pocket wetlands, should be established and planted with native riparian and upland vegetation.

13. Surrounding slopes should be stabilized by planting in order to minimize sediment and pollutants from entering the wetland.

14. A written maintenance plan should be provided and adequate provision made for ongoing inspection and maintenance. Maintenance should be scheduled more often during the first three years after construction.

15. Permanent maintenance easements or other acceptable legal instruments to allow for access to and maintenance of the system are recommended. The easement or other acceptable instrument should cover the entire stormwater system.

**Swale Systems:** These systems are man-made trenches that filter and treat stormwater runoff as part of a treatment train approach. Swale system criteria may vary depending on its place in the treatment train. However, at a minimum, these systems should be designed to meet the following requirements:

1. Required volume should be designed for a 6-month, 24-hour design storm event.

2. No contiguous areas of standing or flowing water within 72 hours following storm event.

3. Peak discharges should be 5 to 10 cfs.

4. Water velocity should be 1.0 to 1.5 ft/s.

5. Maximum design flow depth should be 1 foot.

6. Swale slopes:
   a. Graded as close to zero as possible and still permit drainage
   b. Should not exceed 2%

7. Must have a top width–to-depth ratio of greater than 6:1, or cross-section side slopes of 3:1 (horizontal:vertical) or flatter.

8. Swale length should be at least 100 feet per acre of drainage area.

9. Underlying soils should have high permeability.

10. Swales must be planted with or have stabilized native vegetation suitable for soil stabilization, stormwater treatment, and nutrient uptake.

11. Soil erodibility, soil percolation, slope, slope length, and drainage area must be taken into account, in order to prevent erosion and reduce pollutant concentration of any discharge.

12. Permanent maintenance easements or other acceptable legal instruments to allow for access to and maintenance of the system are recommended. The easement or other acceptable instrument must cover the entire stormwater system.

**Manufactured Stormwater Treatment Systems:** These systems are recommended for use in commercial and industrial developments. The manufactured systems should satisfy the following conditions:

1. Field test data from the southeastern United States should be available. The test data should be from an area with similar rainfall distribution as the project area.

2. Field test data should provide the following results:
   a. Removal of 70-80% of total suspended solids (TSS)
   b. Particle size distribution for TSS removal rates
   c. Conditions under which TSS removal is obtained (storm event, rainfall intensity, etc.)

3. Maintenance information should include how often the system should be serviced.

4. Manufactured systems should be structurally sound and designed for acceptable municipal and commercial traffic loadings.

5. Manufactured systems should not allow inflow or infiltration.

6. Weirs, openings, and pipes should be sized to pass, as a minimum, the storm drain system design storm.

7. Manholes should be provided to each chamber to provide access for cleaning.

8. Treatment train approach incorporating the use of other appropriate best management practices is recommended because efficiency will be increased and maintenance reduced.

9. Permanent maintenance easements or other acceptable legal instruments to allow for access to and maintenance of the system are recommended.

**Detention Practice Criteria:** These criteria are recommended when post-construction runoff volumes should be kept to pre-construction values in order to prevent downstream degradation and flooding. Detention basins and associated outflow structures should be designed to address the 2-year, 5-year, 10-year, 25-year, and 50-year, 24-hour storm events.

Runoff volumes and rates may be calculated using the SCS Runoff Curve Number Method (see Appendix Volume, Appendix A, A-16).

Detention storage may be determined using the Short Cut Floodrouting Method for determining drainage areas and runoffs that fall with the method's limits. If drainage areas and runoffs fall outside the method's limits, other detention sizing methodologies should be used.

**Erosion and Sediment Control Calculations for Estimated Reductions:** The effect of BMPs may be calculated using the USLE methodology (see Appendix Volume, Appendix A, A-2). During construction, the BMP plan should demonstrate the ability to keep sediment yield to 115% of the pre-disturbance sediment yield (15% increase in sediment above pre-disturbance conditions). This is known as performance-based planning. A performance-based plan can demonstrate that selected practices may meet the desired results.

**Effectiveness of Erosion and Sediment Control BMPs:** An estimate of the effectiveness of selecting the more common erosion and sediment control BMPs may be found on Page A-11 (in the Appendix Volume). These estimates can help in performance-based planning.