West Virginia Stormwater Management and Design Guidance Manual

West Virginia Department of Environmental Protection

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Foreword

WVDEP is pleased to present this Stormwater Management and Design Guidance Manual. It is our expectation that this manual will be used to implement stormwater management practices that will help to protect and restore water bodies in communities across the state. This manual is suitable for municipalities and other entities that desire to manage stormwater effectively.

This manual provides design and guidance on implementing stormwater practices that will manage rainfall on site in accordance with West Virginia's small Municipal Separate Storm Sewer System (MS4) General Permit. The recently developed design compliance spreadsheet tool is a companion to this manual to help the designer meet the performance standard criteria contained in the MS4 general permit. This manual is intended to be a stormwater management design resource tool for all WV communities – those that are designated as MS4s as well as non-MS4 communities that desire to manage stormwater more effectively.

This manual contains stormwater management practices that utilize the Runoff Reduction Method, which is a method for using a variety of stormwater best management practices (BMPs) to reduce runoff volumes and associated pollutant loads at development and redevelopment sites. With the right design approach, these practices will be effective in reducing stormwater impacts as well as serving as aesthetic and environmental amenities at development and retrofit sites.

The information presented within this manual is the result of up-to-date research on the science of stormwater management and the combined stormwater expertise of many professionals in West Virginia and across the Country.

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West Virginia Stormwater Management and Design Guidance Manual

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http://www.dep.wv.gov/WWE/Programs/stormwater/MS4/Pages/default.aspx

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Chapter 1. Introduction to the Manual

What's in This Chapter

Section 1.1 provides an overview of the general stormwater management approach for Municipal Separate Storm Sewer Systems (MS4s).

Section 1.2 addresses the purpose of the Manual and its intended audiences, with reference to the MS4 General Permit.

Section 1.3 outlines the stormwater management criteria in the MS4 General Permit and the sections of the Manual that provide more detailed guidance on meeting these criteria.

Section 1.4 explains how the MS4 General Permit intersects with other regulatory drivers for site design and stormwater management.

Section 1.5 directs the user to parts of the Manual that outline the design methodology for the various Best Management Practices (BMPs) that can be used to comply with the standards in the MS4 General Permit.

Section 1.6 points to the detailed design guidance for BMPs contained in the Manual, and includes a pictorial explanation for the BMPs.

Section 1.7 includes a table with a brief overview of each chapter and appendix of the Manual.

Chapter 1. Introduction to the Manual

1.1. Stormwater Management Approach in West Virginia

The urbanization of the landscape creates an increase in the volumes, rates and duration of runoff-related discharges, along with a corresponding increase in pollutant loadings. The traditional design approach to managing these impacts has been based on the peak rate of discharge to control downstream flooding. Unfortunately, this approach ignores the increased frequency, volume, and duration of discharges among other changes in the hydrologic response of the contributing watershed, and fails to protect the physical, chemical and biological characteristics of receiving waters.

There is now a large body of research demonstrating that BMPs that are designed to infiltrate, evapotranspirate, and capture and use stormwater (referred to as runoff reduction techniques) serve to mimic the way natural vegetated landscapes respond to precipitation events. This approach is simultaneously advantageous for protecting the physical, chemical and biological characteristics of receiving waters.

As a result, the West Virginia stormwater management approach establishes runoff volume control as the treatment objective for new development and redevelopment projects. This Manual provides detailed information on how to design sites and stormwater practices to meet this treatment objective.

For more information on West Virginia's stormwater approach, readers are referred to the MS4 General Permit referenced below and associated fact sheet.

http://www.dep.wv.gov/WWE/Programs/stormwater/MS4/Pages/default.aspx

1.2. Purpose and Audiences for the Manual

The primary purpose of this Manual is as a design resource to accompany the MS4 General Permit for stormwater discharges (Permit No. WV0116025). The MS4 General Permit specifies elements of a stormwater management program that must be developed by the local jurisdictions that have been determined by population and/or population density to be owners or operators of an MS4. Following federal discharge permit regulations, the MS4 General Permit contains six "Minimum Measures" that must be included in a local stormwater management program. These Minimum Measures include:

1. Public Education and Outreach
2. Public Involvement and Participation
3. Illicit Discharge Detection and Elimination
4. Controlling Runoff from Construction Sites
5. Controlling Runoff from New Development and Redevelopment (once construction is complete)
6. Pollution Prevention and Good Housekeeping for Municipal Operations

This Manual primarily provides guidance and technical support for Minimum Measure #5: Controlling Runoff from New Development and Redevelopment. The target audiences for the Manual include:

1. Local officials and administrators in designated MS4 communities that must comply with this Minimum Measure.
2. Other localities or entities in West Virginia that choose to develop a stormwater management program or implement stormwater BMPs to protect aquatic resources.
3. Designers, consultants or other individuals or companies that engage in regulated new and/or redevelopment activities.
4. Others interested in stormwater management technical criteria (e.g., businesses, state agency staff, watershed groups, citizens).

Table 1.1 includes suggestions on the Manual sections that may be of particular interest to different types of users. This is not meant to be definitive, as many users will find the Manual content useful for particular purposes.

Table 1.1. Suggestions for How Various Parties Can Use the Manual[1]

MS4 Program Manager	Utilize Chapters 2 and 3 to understand the MS4 General Permit requirements and range of available stormwater BMPs. It is important for program managers to understand all 6 of the Minimum Measures in the MS4 General Permit; therefore, other resources should be used to supplement this Manual. Appendix H is relevant for MS4s that discharge to impaired waters.
MS4 Plan Reviewer (may be same as program manager)	Utilize Chapter 3 to understand the BMP selection process and the specifications in Chapter 4 and checklists in Appendix A to help review plans.
Design Professional/ Consultant	Similar to plan reviewers; the specifications in Chapter 4 are particularly geared to help designers with the proper design of BMPs. Designers may find the design examples in Chapter 6 to be particularly useful. Designers and developers should also become familiar with the site design information in Chapter 2 and Chapter 4 (Specification 4.1), as these are an important means to achieve site compliance.
West Virginia Department of Environmental Protection (WVDEP) Staff	The Manual allows WVDEP to gauge how certain BMP features translate to performance toward achieving the one-inch volume reduction standard. The Manual is a major outreach and technical assistance tool to MS4s and can also be helpful for program reviews.
Currently Non-Regulated Local Government or other Entity (e.g., university, prison, wastewater treatment plant)	Chapter 2 provides a framework for setting up a local program. The individual specifications in Chapter 4 provide an a-la-carte menu for the design of BMPs at any site in West Virginia.
Interested Businesses, Watershed Groups, Citizens, and other Stakeholders	The Manual allows WVDEP to gauge how certain BMP features translate to performance toward achieving the one-inch volume reduction standard. The Manual is a major outreach and technical assistance tool to MS4s and can also be helpful for program reviews.

[1] These are suggested uses for various parties, but not exhaustive, as many types of users will find various sections of the Manual to be helpful for particular purposes.

Chapter 1. Introduction to the Manual

1.3. Stormwater Criteria in the MS4 General Permit, Minimum Measure #5

Controlling runoff from new and redevelopment sites is required at sites that disturb one acre or greater of land in a designated MS4 community. Minimum Measure #5 is a comprehensive standard that protects water quality, as mandated by the federal Clean Water Act, by addressing stormwater runoff with two distinct criteria:

1. Watershed Protection Elements
2. Site and Neighborhood Design Elements

1. Watershed Protection Elements represent a series of criteria that serve to influence site design decisions so as to minimize the impact of the land development process on the natural landscape and receiving waters. The intent of the Watershed Protection Elements is to change and adapt local development codes (e.g., zoning and subdivision ordinances) to reduce stormwater impacts "by design."

- **Chapter 2, Section 2.1** provides a brief overview of the Watershed Protection Elements.
- **Chapter 4, Specification 4.1** outlines several "better site design" practices that can be used at the site scale and also authorized in local development codes.

2. Site and Neighborhood Design Elements address specific stormwater management criteria that apply to new development and redevelopment sites. For any given site, these criteria will result in one or more permanent stormwater BMPs located and designed within the developed landscape that serve to reduce stormwater runoff volume and pollutant loads through infiltration, evapotranspiration, reuse, extended filtration, and other means.

- **Chapter 2, Section 2.1** provides a very brief introduction to the general design objectives of these practices.
- **Chapter 4, Specifications 4.2.1** through **4.2.11** provide detailed guidance on the performance and design criteria for each practice.

Figure 1.1 below provides an introductory pictorial for these practices.

Chapter 1. Introduction to the Manual

1.4. Other Regulatory Drivers That Influence Site Design and Stormwater Management

It is important to acknowledge that, for many sites, there are overlapping regulations at the local, state, and federal levels. In addition to controlling runoff, new and redevelopment projects may have to comply with other requirements related to stormwater, such as floodplains, wetlands, natural streams, and dam safety, among others. Any new or redevelopment project that disturbs one acre or more of land will also be required to obtain coverage under the Construction Stormwater General Permit that provides the details for controlling soil erosion and sedimentation (among other construction related control measures) during the construction process.

While the Manual makes reference to the flood control aspects of stormwater management for larger storms, this is not its intended purpose. In West Virginia, flood control (sometimes referred to as "stormwater detention") remains the purview of local government codes, ordinances, and policies. As such, it should be understood that the practices in this manual will not be a panacea for existing flooding and drainage problems in West Virginia communities. The practices can certainly help with these issues, when they are used in conjunction with other stormwater control and floodplain management measures.

For MS4s, the manual is not intended to supersede existing procedures and policies for the review of site, drainage, or infrastructure plans. The manual can complement existing procedures by specifying the types of practices that can be used to comply with Minimum Measure #5.

- **Chapter 2, Section 2.2** contains an overview of how the MS4 General Permit intersects with other regulatory programs and drivers. MS4 managers, plan reviewers, and design professionals should all be cognizant of the array of programs that may affect a particular site.

Chapter 1. Introduction to the Manual

1.5. Understanding BMP Selection and Design Methodology

Once all the requirements for the new or redevelopment project have been determined, the designer must establish the layout and select the appropriate BMPs that fit the physical characteristics of the site and meet the permit requirements.

The standards and practices described in the Manual (and introduced in Figure 1.1) apply to relatively small storm events (generally one-inch of rainfall or less), because these are the high frequency storms that have the most profound implications for water quality.Therefore, the practices tend to fit into the development infrastructure and may require careful consideration of the limiting design elements such as depth, volume, and long term maintenance.

- **Chapter 3** explains the design methodology and selection criteria for the practices as well as the basis for the sizing (design storms) that will influence the selection of one practice over another. The chapter also references to Design Compliance Spreadsheet, which is a tool for selecting and sizing practices as well as gauging compliance with the performance standards in the MS4 General Permit.

Chapter 1. Introduction to the Manual

1.6. Detailed Design Guidance for the BMPs

The selection and design of the Watershed Protection Elements and the Site and Neighborhood Design Elements require the designer to be familiar with the minimum design elements and features that influence performance.

- **Chapter 4, Specification 4.1** provides a detailed and practical guide to implementing "better site design" practices. These practices can be used at the site scale and also support implementation of the Watershed Protection Elements
- **Chapter 4, Specifications 4.2.1 through 4.2.11** provide detailed guidance on the performance and design criteria for the BMPs for compliance with the Site and Neighborhood Design Elements. **Figure 1.1** provides an overview of the practices.

Figure 1.1. Overview of Stormwater Best Management Practices (BMPs) With Reference to Design Specifications in Chapter 4

Vegetated Filter Strips (Specification 4.2.1)

Vegetated Filter Strips are areas that manage runoff from adjacent developed areas by slowing the runoff and allowing sediment and attached pollutants to settle out, filtering runoff through the vegetation, and infiltrating into the existing or amended soils.

- Applies to small commercial and residential impervious areas.
- Critical design elements include maximum allowable contributing impervious area, slope, and minimum dimensions.

Sheet Flow to Conservation Area (Specification 4.2.1)

Conservation Areas are the "natural" alternative to Vegetated Filter Strips, and consist of areas of natural vegetation (e.g., forest, meadow) that receive runoff as sheetflow from adjacent developed areas. Conservation Areas are often adjacent to streams or natural features, and should be protected with easements or other legal instruments to ensure that they function as a natural buffer system. As opposed to Vegetated Filter Strips, Conservation Areas are outside the limits of disturbance and are not graded.

- Applies to residential and commercial drainage areas.
- Critical design elements include maximum allowable contributing drainage area, slope, minimum dimensions, and long-term management of vegetation.

Simple Impervious Surface Disconnection (Specification 4.2.2)

Simple Impervious Disconnection is a landscape practice that directs runoff from rooftops and other small areas of impervious surface to adjacent pervious areas as sheet flow.

- Small-scale (as compared to filter strips) and intended for residential or small commercial areas;
- Critical design elements include maximum allowable drainage area, slope, and minimum dimensions

Impervious Disconnection with Alternative Practices (Specification 4.2.2)

Alternative Practices are utilized when there is insufficient room to establish sheet flow or meet other Simple Impervious Disconnection criteria (see above).

- Alternative Practices include Soil Amendments, Residential Rain Gardens, Rainwater Harvesting, Stormwater Planters, and Infiltration.
- Effectiveness is based on the same performance mechanisms as the individual practices (covered separately in more detail below).
- Critical design elements include the volume and depth of incorporation of soil amendments, and design elements of the alternative practice

Bioretention (Specification 4.2.3)

Credit: Beckley Sanitary Board

Bioretention is a landscaped practice that uses plants, mulch, and soil to treat runoff. Commonly used in parking lot islands and edges and as part of commercial site plans.

- Can be designed as an infiltration practice or an extended filtration practice (with an underdrain).
- Critical design elements include surface ponding volume, soil media depth, and underdrain. Includes several design variations.

Permeable Pavement (Specification 4.2.4)

Permeable Paving materials include concrete, asphalt, and interlocking pavers that allow runoff to filter through voids into a gravel storage reservoir.

- Can be designed as an infiltration practice, extended filtration practice (with an underdrain and stone sump), or a filtering practice (underdrain without sump).
- Critical design elements include structural load capacity for traffic, surface slope, and limiting the size of the "external" drainage area (adjacent impervious that "runs onto" the permeable pavement).

Grass Swale (Specification 4.2.5)

Grass Swales are designed as conveyance systems with enhanced design features to also provide a level of stormwater treatment and retention.

- Designs can be cost effective when used in place of curb & gutter, pipes, and other conveyance systems.
- Design features include maximum allowable longitudinal slope (or the use of check dams), maximum velocity and depth of flow, large storm conveyance, and trapezoidal cross-section geometry.

Infiltration (Specification 4.2.6)

Infiltration practices utilize temporary surface or underground storage to allow incoming stormwater runoff to infiltrate into underlying soils. Runoff first passes through multiple pretreatment mechanisms to trap sediment and organic matter before it reaches the practice.

- Can be designed as basin, trench, or small-scale practice
- Key design features include runoff pre-treatment, soil permeability testing, and subsoil conditions – such as groundwater. Strict limitations on use at hotspots or Brownfields.

Regenerative Stormwater Conveyance (RSC) System (Specification 4.2.7)

Source: Biohabitats, Inc.

The RSC System is an open-channel conveyance structure that encourages surface flow to transition to shallow groundwater flow through a series of step-pools and riffles and an underlying sand/mulch bed. Can be adapted for moderately steep slopes.

- Can be used to retrofit existing degraded outfalls or for new development in some cases.
- Critical design features include storage volume and peak flow design of riffles and pools, adequate energy dissipation and anchoring system, hydraulic design for large storms, and tying into existing stream channels.

Rainwater Harvesting (Specification 4.2.8)

Rainwater Harvesting systems provide for the capture, storage, and release of rainwater for future beneficial use, either inside or outside the building. Systems usually capture rooftop runoff. Storage tanks can be a variety of materials and either above ground or underground.

- Ideal for sites with a beneficial use of the water, such as irrigation, toilet flushing, cooling towers, vehicle washing, etc.
- Benefits include reducing use of potable water for irrigation and other outdoor uses, flushing, etc.
- Design elements include establishing a reliable water budget and pretreatment.

Vegetated Roofs (Specification 4.2.9)

Credit: WVDEP

Vegetated Roofs are an alternative roof surface that typically consists of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth.

- Captures and temporarily stores stormwater within the growing media.
- Provides significant life-cycle cost benefits to the building and the environment beyond the stormwater reduction.

Filtration Practices (Specification 4.2.10)

Filtration Practices can be designed as either surface or subsurface systems, and utilize a variety of filter media types (e.g., sand, organic filters). Filters are not considered a runoff reduction practice, but can be used to target stormwater hotspot runoff or areas where specific pollutants must be removed.

- Includes a pretreatment separation chamber to remove particulates and oils, and can effectively target hotspot pollutants.
- Design features include sizing of the pre-treatment and filter bed components to prolong the operational life, and adequate maintenance access.

Constructed Stormwater Wetland (Specification 4.2.11)

Constructed Stormwater Wetlands are shallow vegetated depressions with multiple cells of varying depths. Stormwater wetlands are not considered a runoff reduction practice, but can be used for water quality treatment and, in some cases, to meet stormwater detention requirements.

- Design typically includes multiple cells: a pre-treatment forebay, an outlet micro-pool, and at least one or two additional cells separated by a submerged weir or overflow.
- Design features include the number of cells and corresponding pool volume, depth zones, maximum allowable storm ponding depth, and vegetation plan.

1.7. Overview of Manual Content

Table 1.2 provides a quick overview of the content of each chapter and appendix of this Manual.

Table 1.2. Content of the West Virginia Stormwater Management and Design Guidance Manual

Chapter	Description
Chapter 1: Introduction	Basic introduction to the purpose, scope, and content of the Manual
Chapter 2: West Virginia Stormwater Management Regulations	An overview of Minimum Measure #5, other state and federal permits and programs that intersect with stormwater, and a generalized compliance procedure for MS4s and design consultants to follow
Chapter 3: Best Management Practice Selection and Design Methodology	Review of the treatment objectives, performance goals, and capabilities for stormwater BMPs. Includes screening factors to select appropriate BMPs for a site. Outlines the Runoff Reduction Method and use of the Design Compliance Spreadsheet.
Chapter 4: Stormwater BMP Specifications	Detailed specifications for 11 BMPs. These include BMP descriptions, feasibility, sizing, design, materials, construction and maintenance.
Chapter 5: Stormwater Hotspots (land uses or operations that have a higher risk for discharging stormwater pollutants)	Overview of potential stormwater hotspots land uses, BMP design considerations, and checklist to be used by plan reviewers and designers when potential hotspots are involved.
Chapter 6: Design Examples	Illustrates several design examples of applying the method and using various BMPs to achieve the one-inch capture requirement.
Appendix A: Plan Review, Construction, and Maintenance Checklists	Templates for checklists to be used by plan reviewers and designers during all phases of the BMP life-cycle.
Appendix B: Infiltration Testing Guidance	Guidance for conducting field infiltration testing for BMPs designed to infiltrate water. Also includes U.S. Environmental Protection Agency guidance on when BMPs would be considered as Class V Injection Wells requiring an Underground Injection Control permit from WVDEP.

Chapter	Description
Appendix C: Geotechnical Testing Guidelines for Karst Areas	Recommended approach for field testing to ascertain the suitability of certain BMPs in karst.
Appendix D: Soil Amendments	Specifications for soil amendments that can boost the performance of various BMPs.
Appendix E: Determining Peak Flow Rate for One Inch of Rainfall	Guidance on determining the peak flow for one inch of rainfall for the purposes of designing and sizing flow diversions, BMP inlets, and other flow control elements of certain BMPs.
Appendix F: BMP Landscaping & Plant Lists	General guidance on landscaping BMPs and specific plant lists for bioretention, stormwater wetlands, and BMPs in general.
Appendix G: Resources for Design of Wet and Dry Ponds	Wet and dry pond specifications are not included in the Manual because of their limited runoff reduction capabilities. This appendix provides some design resources for those wishing to design ponds to meet local stormwater detention requirements or as part of an overall BMP strategy.
Appendix H: Considerations for Impaired Waters	Guidance for when an MS4 and/or designer should consider impaired waters and/or a TMDL for new development and redevelopment projects.

What's in This Chapter

Section 2.1 provides a brief overview of Minimum Measure #5 – Controlling Runoff from New Development and Redevelopment ("Post-Construction Stormwater").

Section 2.2 outlines how the post-construction standards intersect with other state and federal permits and programs.

Section 2.3 details a general compliance procedure for municipal separate storm sewer systems (MS4s) and other local stormwater programs to administer the post-construction standards.

Section 2.4 references national guidance materials that may assist local programs with the development and implementation of their programs.

Chapter 2. West Virginia Stormwater Regulatory Framework

2.1. Overview of West Virginia's MS4 General Permit – Minimum Measure #5

This section provides a brief overview of the (A) Watershed Protection and (B) Site and Neighborhood Design Elements of Minimum Measure #5 (Controlling Runoff from New Development and Redevelopment). Readers are encouraged to consult the MS4 General Permit and associated fact sheet to obtain more detailed information and specific standards.

A. Watershed Protection Elements

Part II, Section C.b.5.a.i of the MS4 General Permit outlines the Watershed Protection Elements of Minimum Measure #5. This section requires the MS4 or permittee to incorporate six Watershed Protection Elements into local development codes, policies, and ordinances, as well as comprehensive and master plans for land use, transportation, and neighborhoods. The six elements include:

1. Minimize impervious surfaces
2. Preserve, protect, create and restore ecologically sensitive areas
3. Prevent or reduce thermal impacts to streams
4. Avoid or prevent hydromodification of streams and other waterbodies
5. Protect trees and other vegetation
6. Protect native soils

Additional information and resources to review and update development codes and ordinances are provided in Better Site Design: A Handbook for Changing Development Rules in Your Community (CWP, 1998). The handbook can be downloaded at http://www.cwp.org > Publications & Goods > Free Downloads > Better Site Design Publications.

Each of the six Watershed Protection elements is described briefly below. More information is provided in the MS4 General Permit and associated fact sheet.

1. Minimize Impervious Surfaces

The impervious footprint of a development project is dictated, in part, by the development codes of the local jurisdiction. These include subdivision regulations, zoning regulations, parking and street standards and drainage requirements. Often, these codes require or allow excessive impervious cover through wide residential streets, large commercial parking lots, and large cul-de-sacs, among other practices. Essentially, the codes act as *de facto* stormwater regulations, even though they were not created for that purpose. This watershed protection element encourages updating and making changes to development codes in order to reduce the amount of impervious cover created during the development process (**Figure 2.1**). Examples include reduced road width standards (at least in certain districts), parking lot maximum standards (or requiring pervious surfaces above a certain threshold), and reducing the use and required radius of culs-de-sac.

Figure 2.1. Pervious pavers used for overflow parking
(Source: National Nonpoint Education for Municipal Officials Network)

2. Preserve, protect, create and restore ecologically sensitive areas

During the development process, ecologically sensitive areas that provide water quality benefits and serve critical watershed functions should be protected. These include headwater and perennial streams, wetlands, 100-year floodplains, and steep slopes. These areas should be identified as part of a natural resources inventory prior to conducting a development layout or design. Regional approaches, such as watershed/green infrastructure plans or area-wide plans (**Figure 2.2**), are recommended because they identify regionally-significant and interconnected ecologically sensitive areas, and then use site-level plans to implement the findings through incentives, regulations, and policies (e.g., stream buffer standards).

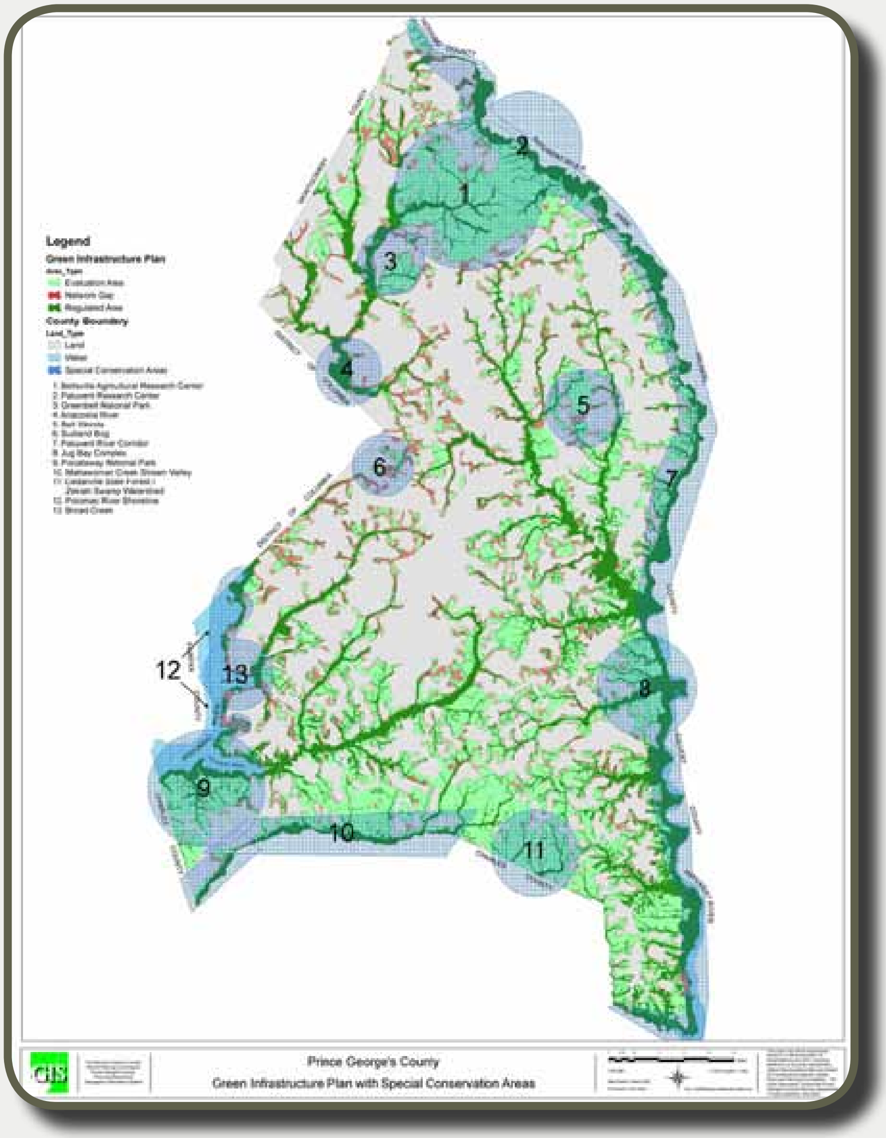


Figure 2.2 Green infrastructure plans identify significant resources and ecologically sensitive areas for protection in advance of site development (Source: Prince George's County Planning Department)

3. Prevent or reduce thermal impacts to streams

Preventing or reducing thermal impacts to streams is important to protect temperature sensitive aquatic species. West Virginia is fortunate to have over 1,000 streams that contain segments supporting trout populations. These streams provide a valuable recreational fishery contributing over $180 million to the state's economy every year. Just a few degrees of temperature alteration during critical times can be detrimental to trout survival.

Stream warming can occur from a lack of vegetated stream buffers and increased temperature of stormwater runoff discharges from impervious surfaces and stormwater ponds. During the summer months, stormwater that flows over impervious surfaces (such as parking lots or driveways) or that is detained within stormwater ponds is warmed before it flows to receiving streams. Practices that should be used to reduce thermal impacts from stormwater include disconnecting or directing runoff from impervious surfaces to pervious areas, especially to stormwater practices that have a subsurface component, such as bioretention with a relatively deep (e.g., three feet) soil media layer (**Figure 2.3**). Additionally, requiring vegetated stream buffers provides tree canopy to shade and cool the stream.

Figure 2.3 Parking lot runoff directed into a bioretention facility reduces thermal impacts (Source: National Nonpoint Education for Municipal Officials Network)

4. Avoid or prevent hydromodification of streams and other waterbodies

Modification of stream and waterbody hydrology should be avoided or prevented during development (**Figure 2.4**). Piping, filling or burying of streams alters the natural stream processes and disrupts the physical habitat. Site designs should seek to "avoid and minimize" these impacts through careful design and properly-conceived mitigation that accounts for stream hydrologic and hydraulic processes.

Figure 2.4. Streams provide water quality benefits such as nutrient processing and groundwater recharge and should be protected from development impacts (Source: Center for Watershed Protection)

5. Protect trees and other vegetation

During development, mass clearing and grading removes trees and vegetation. Trees and other vegetation provide important benefits that include stabilizing soil and preventing erosion, enhancing the function of stormwater management practices, reducing construction and maintenance costs, and improving aesthetics. The loss of trees and other vegetation can be minimized through local regulations or standards that:

- Limit clearing of native vegetation
- Require forest conservation
- Require forested stream buffers (**Figure 2.5**)
- Promote development that conserves open space (this open space or green space can often be used for stormwater management as well)
- Include provisions for physically protecting trees during construction
- Provide stormwater credits for tree conservation and planting
- Require tree planting in landscaped areas or as part of reforestation incentives or regulatory approach

To obtain additional resources on forest friendly development, visit the Watershed Forestry Resource Guide website http://www.forestsforwatersheds.org/

Figure 2.5. Preservation of forested stream buffers during development (Source: Center for Watershed Protection)

6. Protect native soils and topsoil

During the development process, native soils should be protected to the extent possible. Wholesale topsoil stripping and compaction of soils should be prevented, especially soils that may be most conducive for stormwater absorption and infiltration. This practice helps reduce stormwater runoff, as undisturbed native soils have higher infiltration rates than soils that are cleared and compacted during development. Erosion and sediment control ordinances can be modified to reduce clearing and grading of forests and native vegetation. Also, phased site clearing should be encouraged to reduce mass clearing and grading and minimize exposed soils. In addition, site fingerprinting should be encouraged; this means limiting disturbance to the minimum area necessary for the construction of the buildings, roadways and a safety setback, while preserving other areas as green space (**Figure 2.6**).

Figure 2.6. During construction of this subdivision, clearing was limited to the minimum area necessary, protecting native soils (Source: National Nonpoint Education for Municipal Officials Network)

B. Site and Neighborhood Design Elements

Part II, Section C.b.5.a.ii of the MS4 General Permit outlines the Site and Neighborhood Design Elements of Minimum Measure #5.

The general objectives of this section are stated as follows:

"The permittee shall develop a program to protect water resources by requiring all new and redevelopment projects to control stormwater discharge rates, volumes, velocities, durations and temperatures. These standards shall apply at a minimum to all new development and redevelopment disturbing one acre or greater, including projects less than one acre that are part of a larger common plan of development or sale."

The specific performance standard of this section contains the primary design goal for post-construction stormwater designs and practices:

"Site design standards for all new and redevelopment that require, in combination or alone, management measures that keep and manage on site the first one inch of rainfall from a 24-hour storm preceded by 48 hours of no measurable precipitation. Runoff volume reduction can be achieved by canopy interception, soil amendments, evaporation, rainfall harvesting, engineered infiltration, extended filtration and/or evapotranspiration and any combination of the aforementioned practices."

Runoff Reduction Practices Can Meet The One-Inch Performance Standard

The types of practices that achieve the one-inch reduction are known as "runoff reduction practices." Chapter 4 provides detailed specifications for a range of runoff reduction practices that achieve this particular level of runoff reduction and associated pollutant removal. The volume of water that must be treated by these practices is known as the design "Target Treatment Volume," and equates to one-inch of rainfall multiplied by the runoff coefficient for the site. Chapter 3 explains the design methodology for calculating the Target Treatment Volume and using selected runoff reduction practices to manage this volume.

The Site and Neighborhood Design section of the MS4 General Permit also addresses the following elements of a local stormwater program:

- Special treatment for "stormwater hotspots," which are sites or facilities with an increased potential for pollutant loadings, such as vehicle maintenance facilities (**Figure 2.7**).
- Incentive standards to reduce the volume of water that must be managed (the Target Treatment Volume) by using certain development or redevelopment strategies. There are five incentive standards: (1) redevelopment, (2) Brownfield redevelopment, (3) high density development, (4) vertical density, and (5) mixed use and transit-oriented development. Each incentive can reduce the one-inch reduction standard by 0.2 inches, up to a maximum of 0.75 inches.
- Off-site compliance options for projects where it is documented that the full runoff reduction requirement for a site cannot be met. There are two off-site options: (1) off-site mitigation projects, and (2) payment in lieu of constructing on-site practices.
- The requirement to incorporate runoff reduction practices into public street and parking lot modification or reconstruction projects.
- Standards for an MS4's plan review, approval, and enforcement program.
- A requirement for maintenance agreements and plans for all approved stormwater management practices.
- Standards for MS4s to inspect, inventory, track, and report on stormwater management practices.

Figure 2.7. Public works yards are one type of stormwater hotspot due to the high number of potential polluting materials stored outside (Source: Center for Watershed Protection)

Section 2.3 provides additional guidance on several of these programmatic elements and a general procedure for an MS4 or local stormwater program to verify compliance with the MS4 General Permit.

Chapter 2. West Virginia Stormwater Regulatory Framework

Section 2.2. Other State and Federal Programs That Influence Local Stormwater Programs

The MS4 General Permit does not function in isolation. There are several other state and/or federal regulatory programs (or "regulatory drivers") that will influence how stormwater is managed by an MS4 or other local program. While the MS4 is not responsible for administering or enforcing state or federal permits, it may be placed in the role of integrating or coordinating state and federal permits with local stormwater ordinances and standards for certain new development and redevelopment projects. For instance, the MS4 may need to coordinate approval of the stormwater plan with other approvals for activities in streams and/or wetlands, underground injection, or dam safety (to name just a few).

Table 2.1 outlines some of the more prominent state and federal regulatory drivers that may intersect with local stormwater programs. While the table is not exhaustive in this regard, it does highlight the degree of coordination that may be necessary in certain instances. The table provides a brief description of each program along with its link to local stormwater programs and the main contact agency.

Table 2.1. Other Regulatory Drivers That Influence Local Stormwater Programs in West Virginia

Regulatory Driver	Description & Link With Local Stormwater Program
State and Federal Programs	
Construction Stormwater General Permit	Applies to all sites with disturbance of one acre or greater to regulate sediment discharges into waters of the state. Projects disturbing at least one but less than three acres are required to submit a Notice of Intent (NOI) application. Projects disturbing three acres or greater must submit a Site Registration Application Form. The permit is reissued on a periodic basis (e.g., every five years). This permit program is accompanied by the West Virginia Erosion and Sediment Control Best Management Practice Manual (2006). Part II, Section C.b.4 of the MS4 General Permit also addresses discharges from construction sites. Link With Stormwater Program: This permit provides an opportunity for local programs to coordinate construction and post-construction stormwater in plan review, inspection, and maintenance. Contact: West Virginia Department of Environmental Protection (WVDEP), Division of Water and Waste Management http://www.dep.wv.gov/WWE/Programs/stormwater/csw/Pages/home.aspx
Multi-Sector Stormwater General Permit (Industrial Activities)	In order to minimize the impact of stormwater discharges from industrial facilities, the National Pollutant Discharge Elimination System (NPDES) program includes an industrial stormwater permitting component. Operators of industrial facilities included in one of the 20 categories of stormwater discharges associated with industrial activity that discharge or have the potential to discharge stormwater to an MS4 or directly to waters of the state require authorization under a NPDES industrial stormwater permit. Link With Stormwater Program: This permit provides an opportunity for local programs to coordinate stormwater review for industrial operations. Part II, Section C.b.6 of the MS4 General Permit also addresses Pollution Prevention & Good Housekeeping for Municipal Operations, including industrial activities. Contact: WVDEP, Division of Water and Waste Management http://www.dep.wv.gov/WWE/Programs/stormwater/multisector/Pages/home.aspx

Table 2.1. Other Regulatory Drivers That Influence Local Stormwater Programs in West Virginia

Regulatory Driver	Description & Link With Local Stormwater Program
Other NPDES Permits -- Non-Stormwater General Permits & Individual Permits	A variety of industrial and wastewater operations are covered through both general and individual permits that authorize the discharge of wastewater to waters of the state. Potential examples include car washes that have a discharge to state waters, water treatment facilities, discharges from highway or municipal maintenance facilities, and other discharging facilities (see link below for list of permitted activities). Link With Stormwater Program: It may be necessary for local programs to coordinate review for certain types of facilities or sites that must obtain both local and state permits. Contact: WVDEP, Division of Water and Waste Management http://www.dep.wv.gov/WWE/permit/general/Pages/default.aspx
Underground Injection Permits	WVDEP regulates non-mining Class V injection wells. In certain and very specific circumstances, stormwater best management practices (BMPs) may be subject to Underground Injection Control (UIC) permits, particularly infiltration practices that have a subsurface fluid distribution system (e.g., underdrain that does not discharge to the surface or the storm drain system) or that are deeper than their widest dimension. However, most standard stormwater BMPs are not considered to be Class V wells. Link With Stormwater Program: The local program will likely have to coordinate potential UIC permit coverage of a small number of qualifying practices with WVDEP or, more importantly, guide the design of those practices to avoid being considered a Class V well. Contact: WVDEP, Division of Water and Waste Management http://www.dep.wv.gov/WWE/permit/uic/Pages/default.aspx

Table 2.1. Other Regulatory Drivers That Influence Local Stormwater Programs in West Virginia

Regulatory Driver	Description & Link With Local Stormwater Program
Floodplain Permits	To date (2011), 55 counties and 214 communities in West Virginia have voluntarily adopted and are enforcing local floodplain management ordinances in concert with the National Floodplain Insurance Program. Local ordinances can include a flood map that designates floodplain areas, and establishes a permitting system to regulate new development in the floodplain. Link With Stormwater Program: If at all possible, stormwater practices should not be located within a floodplain. The local program will have to coordinate reviews for any practices that are authorized to be located in the floodplain. Also, preservation, protection, and/or restoration of floodplains and riparian corridors are specifically mentioned as a Watershed Protection element in the MS4 General Permit (Part II, Section C.b.5.a.i). Contact: West Virginia Division of Homeland Security and Emergency Management http://www.dhsem.wv.gov/mitigation/floodplain/Pages/default.aspx
Stream Activity Applications	Public Land Corporation applications are for the protection of water quality and aquatic life and are required when working or placing equipment in the stream. West Virginia Division of Natural Resources (WVDNR) fisheries biologists review applications to ensure high quality streams are protected and that activities, such as installation of culverts and re-channelizing streams, do not have detrimental effects on habitat. Link With Stormwater Program: The MS4 General Permit directs MS4s to "seek to avoid or prevent hydromodification of streams and other water bodies caused by development, including roads, highways, and bridges" [Part II, Section C.b.5.a.i(4)]. Contact: WVDNR, Office of Land & Streams http://www.wvdnr.gov/REM/PLC.shtm

Table 2.1. Other Regulatory Drivers That Influence Local Stormwater Programs in West Virginia

Regulatory Driver	Description & Link With Local Stormwater Program
Clean Water Act Section 404 Permit and 401 Certification	The physical alteration of water bodies in West Virginia, including wetlands and streams, is regulated by federal and state statutes under Section 401 (Certification) and Section 404 (Permits) of the Federal Clean Water Act. The U.S. Army Corps of Engineers regulates the discharge of dredged and/or fill material in waters of the U.S. Section 401 of the Clean Water Act requires that any applicant for a Section 404 permit also obtain a Water Quality Certification from the state. The purpose of the certification is to confirm that the discharge of fill materials will be in compliance with the state's applicable Water Quality Standards. Link With Stormwater Program: See above for "Stream Activity Applications." The effort on behalf of the MS4 to "avoid or prevent hydromodification of streams and other water bodies" overlaps with the intent of the Section 404 permit to "avoid and minimize" impacts. Contact: U.S. Army Corps of Engineers, WVDEP, WVDNR
Section 438 of the Energy Independence and Security Act (EISA)	Section 438 of EISA states that "the sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow." In 2009, the U.S. Environmental Protection Agency (EPA) issued technical guidance for implementing this provision of EISA. Link With Stormwater Program: The local program should be aware of the EISA requirements and guidance for federal facilities that may be constructed or redeveloped within the community. The local program may not have authority to review federal projects, but these projects often seek to coordinate with any local requirements. In addition, federal facilities can often discharge into the MS4; therefore the MS4 should be aware of this discharge and have the ability to address adverse impacts to their system. Contact: U.S. Environmental Protection Agency http://www.epa.gov/owow/NPS/lid/section438/

Table 2.1. Other Regulatory Drivers That Influence Local Stormwater Programs in West Virginia

Regulatory Driver	Description & Link With Local Stormwater Program
Combined Sewer System Long-Term Control Plan	This program requires communities with combined sewer systems to develop a plan to eliminate combined sewer overflows (CSOs) to ultimately comply with water quality standards. Link With Stormwater Program: Some communities have both an MS4 and a combined sewer system, and management practices should be coordinated. For instance, practices that limit the volume of stormwater discharges can also help reduce the incidence of overflows. In addition, stormwater treatment practices, such as street sweeping and catch basin cleaning, can reduce floatables and sediment and thus reduce overflows. Contact: WVDEP, Division of Water and Waste Management http://www.dep.wv.gov/wwe/permit/individual/pages/default.aspx#mdwastewater
Total Maximum Daily Load (TMDL)	TMDLs provide a system to develop studies and plans for stream segments that do not meet water quality standards. The Chesapeake Bay TMDL and the Watershed Implementation Plan (WIP) applies to the portion of the state that drains to the Potomac or James Rivers and subsequently the Chesapeake Bay. Other TMDLs apply across the state based on Hydrologic Groups. Link With Stormwater Program: There is a growing trend to link TMDL requirements with MS4 permits. There is still uncertainty about this link, but it may take the form of implementing stormwater retrofits on existing developed land, using BMPs that address a pollutant of concern, or developing pollutant load limits for new development and redevelopment. Contact: WVDEP, Division of Water and Waste Management, Watershed Management http://www.dep.wv.gov/WWE/watershed/TMDL/Pages/default.aspx

Table 2.1. Other Regulatory Drivers That Influence Local Stormwater Programs in West Virginia

Regulatory Driver	Description & Link With Local Stormwater Program
Dam Safety Program	Construction, modification, or removal of a dam under state jurisdiction requires a Certificate of Approval. Safety standards set by West Virginia's Dam Safety Rule (Rule) must be met before issuance of a certificate. Annual renewal of certificates helps to ensure that dams are maintained in a safe condition. In general, the Rule applies to dams that equal or exceed 25 feet in height and 15 acre-feet of storage capacity, or six feet in height and 50 acre-feet of storage capacity. Link With Stormwater Program: It is possible that large stormwater ponds and basins may trigger a dam safety certificate, and coordinated review would be necessary. Contact: WVDEP, Division of Water and Waste Management, Environmental Enforcement http://www.dep.wv.gov/WWE/ee/ds/Pages/default.aspx

Chapter 2. West Virginia Stormwater Regulatory Framework

Section 2.3. General Compliance Procedure For New Development & Redevelopment Projects

As noted above, Part II, Section C.b.5.ii of the MS4 General Permit establishes general standards for plan review, approval, and enforcement for Minimum Measure #5 -- Controlling Runoff from New Development and Redevelopment (see Table 2.2).

The successful implementation of this program requires coordinated efforts by the both the MS4/local stormwater program and the owner or applicant for new development and redevelopment projects. The program elements include preparation, submittal, review, and approval of stormwater plans as well as construction, inspection, and maintenance of post-construction stormwater BMPs.

Figure 2.8 illustrates a general flowchart by which both the MS4 and the project owner/applicant can verify compliance with the provisions in the MS4 General Permit. The left side of the figure refers to activities or actions undertaken by the MS4/local program, and the right side refers to activities and actions by the project owner/applicant.

It is important to note that the flowchart in Figure 2.8 is a typical depiction of this process. An individual local program may have other plan review and inspection procedures and policies that take precedence, and that achieve similar outcomes. Local governments can adapt or modify individual components of the process in the figure to develop a local stormwater program and compliance procedures.

Table 2.2. West Virginia MS4 General Permit Language for Plan Review, Approval, and Enforcement [Part II, Section C.b.5.a.ii.B]

Plan Review, Approval and Enforcement. To ensure that all new development and redevelopment projects conform to the standards stipulated in Part II, Section C.b.5.ii, the permittee shall develop project review, approval and enforcement procedures. The review, approval and enforcement procedures shall apply at a minimum to all new development and redevelopment disturbing greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale, and shall include:

(1) Requirements to submit for review and approval a pre-application concept plan that describes how the performance standards will be met. A pre-application meeting attended by a project land owner or developer, the project design engineer, and municipal planning staff to discuss conceptual designs may also meet this requirement.

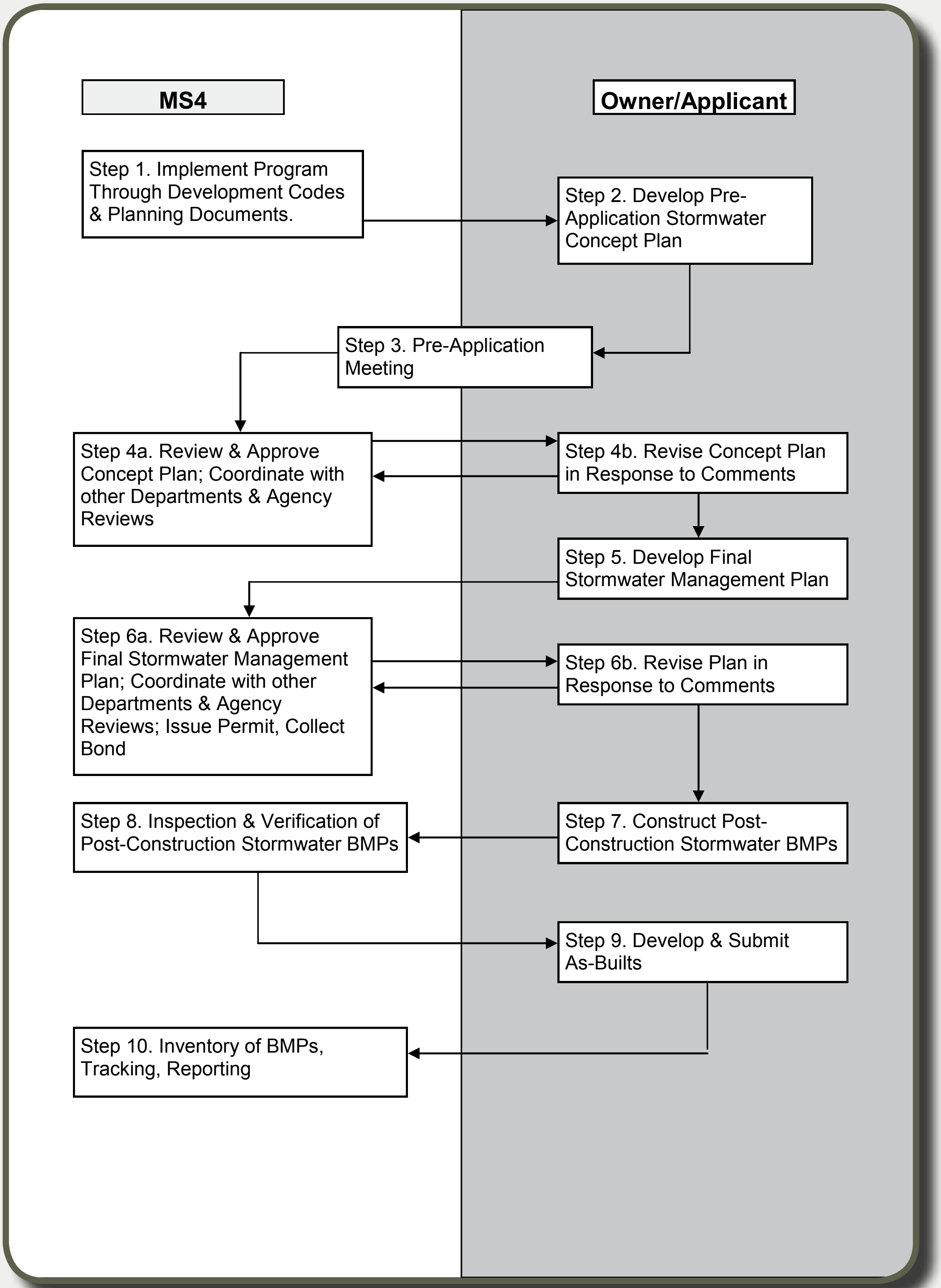
(2) Development of procedures for the site plan review and approval process(es) that include inter-departmental consultations, as needed, and a required re-approval process when changes to an approved plan are desired.

(3) A requirement for submittal of "as-built" certifications within 90 days of completion of a project.

(4) A post-construction verification process to ensure that stormwater standards are being met, that includes enforceable procedures for bringing noncompliant projects into compliance.

(5) A description of a program to educate both internal staff and external project proponents of the requirements of Part II, Section C.b.5 of this permit.

Figure 2.8. Typical Compliance Pathway for the Minimum Control Measure # 5 -- Controlling Runoff from New Development and Redevelopment



The remainder of this section describes each step in **Figure 2.8** in more detail.

Step 1: Implement Program Through Development Codes & Planning Documents

Who Does This Step?

- The MS4 or local stormwater program

When Does This Step Occur?

- At initial program development prior to plans being submitted

Description:

Minimum Measure #5 contains provisions for Watershed Protection and Site and Neighborhood Design (see Section 2.1). These provisions must be translated into local codes, policies, and planning documents so that they become design standards for new development and redevelopment projects. The Watershed Protection provisions are likely to be incorporated into local zoning and/or subdivision codes because they relate to site design, reduction of impervious cover and protection of sensitive areas, trees and vegetation, and soils. The Site and Neighborhood Design provisions can be incorporated into the local zoning and/or subdivision codes or into a stand-alone stormwater or environmental code. This step is a prerequisite to having a functioning stormwater program that follows the stipulations of the MS4 General Permit.

Step 2: Develop Pre-Application Stormwater Concept Plan

Who Does This Step?

- The owner/applicant/design engineer for a new development or redevelopment project that disturbs one-acre or greater (including projects of less than one acre that are part of a common plan of development or sale that will disturb, in total, one acre or more).

When Does This Step Occur?

- Very early in the site planning process, before infrastructure and lot configurations are locked down.

Description:

The MS4 General Permit provides for the "review and approval of a pre-application concept plan that describes how the performance standards will be met." The Concept Plan provides the opportunity for the applicant to put basic stormwater design ideas and practices on paper before expending time and resources preparing more complex engineered plans and computations. This step can help both the local stormwater program and the developer avoid problems that could occur if the plan is submitted later in the process. The Concept Plan should include:

- Graphical Elements showing site design features in accordance with the Watershed Protection provisions (as reflected in local development codes as part of **Step 1** above). This may include alternative conceptual site designs or other graphical tools. The graphical element should also show the general type, location, and size or proposed stormwater BMPs that will be used to meet the Site and Neighborhood Design performance standard to manage to first one-inch of rainfall. Stormwater BMPs can be shown as bubbles or "blobs" on the plan, although some effort should be made to demonstrate that they are sized adequately to capture the design volume.
- Narrative & Computation Elements that describe:
  (a) Site design incentives from Part II, Section C.b.5.ii.A.3 of the MS4 General Permit that are proposed to reduce the Target Treatment Volume (e.g., redevelopment, Brownfield redevelopment, high density, vertical density, mixed use and transit oriented development).

(b) Conceptual or preliminary computations that show the Target Treatment Volume (after site design incentives are taken) and the stormwater BMP types and sizing necessary to control it. The best way to do this is using the Design Compliance Spreadsheet described in **Chapter 3 of the Manual**. A project-specific version of the spreadsheet should be included in the submittal package.

(c) Other narrative elements that will assist the plan review in understanding how the concept plan complies with the provisions of the MS4 General Permit, as reflected in local development codes.

Step 3: Pre-Application Meeting

Who Does This Step?

- Both the MS4/local stormwater program AND the owner/applicant along with the project design engineer.

When Does This Step Occur?

- Soon after the owner/applicant prepares the Concept Plan outlined in **Step 2**. However, it may be advantageous for the parties to meet in the office or in the field prior to completion of the Concept Plan if site design and stormwater discussions would aid the applicant in preparing the Concept Plan.

Description:

The intent of this meeting is to discuss site compliance issues and allow for constructive interaction between the parties. It is hoped that this meeting will result in a higher quality submittal and a faster compliance schedule. The meeting is particularly relevant to discuss site design issues that can reduce the Target Treatment Volume, application of site design incentives, and the most applicable stormwater BMPs for the site.

Step 4a: Review & Approve Concept Plan; Coordinate with Other Departments & Agency Reviews

Who Does This Step?

- MS4/local stormwater program

When Does This Step Occur?

- Within the specified time for review of the Concept Plan after accepting the submittal as complete.

Description:

The approval of the Concept Plan means that there is enough information to confirm that the Final Stormwater Management Plan (see **Step 5**) is very likely to achieve compliance. To do this, the plan reviewer will need to review the graphical elements and ensure that they are consistent with the project-specific Design Compliance Spreadsheet, computations, and other narrative elements.

The Concept Plan is the Time to Coordinate Internal & External Reviews

There are several other important coordination steps that should be done at this point:

- Coordinate the review with other internal reviews, such road and drainage plans, subdivision plats, water and sewer, floodplains, erosion control and grading, and groundwater/wellhead protection. This is a chance to vet and resolve possible internal conflicts that may limit or omit the use of certain practices (including site design practices, such as narrow streets, alternative site layouts, parking materials, etc.).
- Coordinate the review with external reviews, especially for plans that are subject to state or federal reviews, such as wetland and stream permits, other discharge permits, requirements for federal projects (e.g., ERISA), dam safety permits, and other required permits for the site (see **Table 2.1**).

Step 4b: Revise Concept Plan in Response to Comments

Who Does This Step?

- Owner/applicant and design engineer

When Does This Step Occur?

- After receiving comments, if any, from the plan reviewer.

Description:

The design engineer revises the Concept Plan components in response to reviewer comments. The objective at this point is to ensure that there is enough information to ensure a complete and compliant Final Stormwater Management Plan. Engineering details and final computations are not expected at the concept plan stage.

Step 5: Develop Final Stormwater Management Plan

Who Does This Step?

- Owner/applicant and design engineer

When Does This Step Occur?

- After approval of Concept Plan.

Description:

Using the approved Concept Plan as a framework, the Final Stormwater Management Plan is developed. A typical plan submittal package includes the items listed in **Table 2.3**. It should be noted that the final stormwater management plan is often coordinated or combined with other final plans, such as grading and drainage, erosion control, utilities, and road plans. The actual content for final plans is dictated by the local program requirements; the items in **Table 2.3** are guidelines.

Table 2.3. Recommended Computation Submittal Package (derived from Claytor, 2006)

Graphical
• Vicinity map • Plan view showing BMP locations, sizing, post-development drainage areas, and layout with storm sewer and other utilities • For each BMP: necessary cross-sections and profiles with elevations of critical components to ensure that BMP can be properly constructed • Graphical portrayal of coordination with erosion and sediment control measures (e.g., will any be converted to permanent BMPs at the completion of construction) • Typical details and notes • As relevant to the stormwater design, soil survey, geology, slope, land cover, and other maps
Narrative & Computations
• Cover: Project title, client, nature of computations • Copy or summary of Design Compliance Spreadsheet for the project • able of proposed BMPs with Target Treatment Volume for drainage area (one-inch capture), volume provided, and sizing • Watershed delineation for pre- and post-development conditions with travel times (times of concentration), land use, and soils • Narrative of stormwater management system • Summary of hydrology and hydraulics • Table of drainage areas, curve numbers (CNs), time of concentration, and peak discharges (pre- and post-construction) that summarizes the performance of proposed stormwater measures. • Detailed hydraulic calculations (hydraulic calculations of outlet orifice, weirs, spillways, etc.) • Hydrologic analyses (e.g., area CN calculation spreadsheets, practice sizing equations, model run outputs) • Other calculations (e.g., inflow channel sizing, outfall channel, downstream analyses, dam breach assessments, filter diaphragm sizing, groundwater mounding analyses, structural calculations) • Site photographs, as applicable • List of permit requirements and how project is in compliance (including permits needed for construction stormwater; streams and wetlands, floodplains, stream buffers, wellhead protection, dam safety and other relevant permits) • Supporting data (as applicable) • Soil test pits and/or borings; results of infiltration tests • Pollutant monitoring data • Groundwater elevation data • Habitat evaluations • Tree surveys • Threatened and endangered species • Receiving water classification (e.g., 303(d) listing, cold-water fishery)

Supporting Documents

- Maintenance agreement
- Maintenance plan for each BMP (or type of BMP)
- Submittal fees (as applicable to the local program)
- Engineer's certification statement
- Documentation of other permits (e.g., wetlands, floodplain)
- Performance bond (as applicable to the local program)

Steps 6a: Review and Approve Final Stormwater Management Plan; Coordinate with Other Departments & Agency Reviews; Issue Permit; Collect Bond

Who Does This Step?

- MS4/local stormwater program.

When Does This Step Occur?

- Within the specified time for review of the Final Stormwater Management Plan after accepting the submittal as complete.

Description:

This is a detailed review to verify compliance with the standards in MS4 General Permit and the local ordinance. The reviewer should verify that the information submitted in the Design Compliance Spreadsheet matches up with information shown on the plan. The plan reviewer can at this point develop specific comments that need to be addressed in order for the plan to receive approval (see Step 6b below). Final approval requires coordination with other internal and external reviews for the project. Some programs specify that a performance bond be posted as a condition of final approval.

Step 6b: Revise Final Plan in Response to Comments

Who Does This Step?

- Owner/applicant and design engineer

When Does This Step Occur?

- After receiving comments from the plan reviewer.

Description:

The design engineer responds to comments from the reviewer. This is an iterative step with Step 6a.

Step 7: Construct Post-Construction Stormwater BMPs

Who Does This Step?

- Owner/applicant and site contractor

When Does This Step Occur?

- After receiving final approval of the Stormwater Management Plan, posting performance bond (if required by the local program), receiving all necessary permits and approvals, and following the proper construction/BMP installation sequence as specified on the plan.

Description:

Depending on the BMP, a very specific construction sequence should be followed. In particular, BMPs that have a filter media, rely on infiltration into the underlying soil, and/or that are vulnerable to construction sediments should only be installed once the contributing drainage areas reach a specified level of stabilization. The Final Stormwater Management Plan should be coordinated with the grading and drainage and erosion and sediment control plans to ensure that the installation of permanent stormwater BMPs follows the proper sequence. It is often helpful for the design engineer to have a role in ensuring that post-construction BMPs are built according to the plan.

Step 8: Inspection & Verification of Post-Construction Stormwater BMPs

Who Does This Step?

- MS4/local stormwater program.

When Does This Step Occur?

- Post-construction BMPs should be inspected at critical stages during installation, and a final inspection should be conducted to verify that the BMP is installed in accordance with the plan and/or any approved field changes.

Description:

Many BMPs do not perform as intended due to improper installation and construction issues. **Figure 2.9** illustrates several common construction and installation pitfalls, using bioretention as an example. Inspection frequency depends on the type of practice. Practices with multiple materials and layers, subgrade construction, and multiple-step construction sequences usually require more interim inspections. One of the most important roles for inspectors during BMP installation is to ensure that drainage areas are adequately stabilized in order to install post-construction BMPs. For instance, premature installation of bioretention soil media is one of the major causes of failure of these practices. _

For more information on inspection and verification and post-construction BMPs during initial installation, see Chapter 8 in *Managing Stormwater In Your Community* (CWP, 2008). See **Section 2.4** at the end of this chapter for links to download this manual.

Appendix A of this Manual contains checklists for various BMPs that can be used as a tool for the inspection process.

Figure 2.9. Common issues with installation of post-construction BMPs, using bioretention as an example (Source: Center for Watershed Protection).

Bioretention swale, installed too early during active construction, has become clogged with sediment.

Bioretention area does not drain because of improper soil media, soils compacted during installation, and/or filter fabric under media

Curb inlets to bioretention swale have eroded because of improper sizing of stone.

High plant mortality has occurred because improper species were substituted during construction.

Site runoff by-passes bioretention swale because of small elevation changes during construction.

Some site runoff by-passes bioretention because of inadequate slope of filter strip.

Step 9: Develop & Submit As-Builts

Who Does This Step?

- Owner/applicant, site contractor and/or design engineer.

When Does This Step Occur?

- Once the final sign-off occurs from the inspector. The MS4 General Permit requires that "as-built certifications" be submitted "within 90 days of completion of a project."

Description:

Once BMP installation is complete, as verified by the inspector, the applicant's design consultant prepares an as-built plan for each stormwater BMP based on actual site conditions. This plan can take the form of a "red-lining" approved design plan to note any discrepancies. The design professional also certifies that the constructed BMP meets or exceeds plan specifications. It is important for the as-built plan to confirm:

- Placement of BMPs within easements
- Proper sizing, dimensions, and materials
- Elevations of inlets, outlets, risers, embankments, etc.
- Vegetation per the planting plan or any approved substitutions
- Location of permanent access easements for maintenance

Step 10: Inventory of BMPs, Tracking, Reporting

Who Does This Step?

- MS4/local stormwater program.

When Does This Step Occur?

- Ongoing, as part of a BMP maintenance, tracking, and reporting program.

Description:

The proper installation of a post-construction BMP is only the beginning of its life-cycle. Long-term maintenance and operation are needed to ensure continued performance and functioning. In this regard, the MS4 General Permit contains provisions for maintenance agreements, inventory, inspections, and tracking of BMPs, and annual reporting. **Table 2.4** outlines the MS4 General Permit sections for each of these topics. The MS4 General Permit should be consulted for the full details concerning these program elements.

Table 2.4. Outline of MS4 General Permit Sections Pertaining to Long-Term Tracking, Inspection, and Reporting for Post-Construction BMPs

Topic	**MS4 General Permit Section (Part II)**	**Brief Description[1]**
Maintenance Agreements	Section C.b.5.ii(C)	Specifies that owners/operators submit maintenance agreement and maintenance plan, along with proper documentation including transfer of maintenance responsibility. Authorizes MS4 to conduct inspections and performance of corrective actions if necessary.
Inventory and Tracking of Management Practices	Section C.b.5.ii(D)	Requires MS4 to establish an inventory and tracking system (e.g., with GIS) that begins at plan review and extends through long-term maintenance. Specifies minimum content for tracking system. Tracking includes "source control management practices" as well as structural or non-structural "treatment control practices."
Stormwater BMP Inspections	Section C.b.5.ii(E)	Requires MS4 to establish a long-term maintenance inspection and enforcement program, including an inspection calendar (all BMPs inspected at least once during permit cycle), content of inspection reports, and an enforcement and response plan.
Reporting	Section C.b.5.ii(F)	An outline of the basic information to be included in the MS4's Annual Report.

[1] *Consult the full text of the MS4 General Permit and associated fact sheet for all of the details concerning these provisions.*

2.4. National Guidance for Building Effective Post-Construction Stormwater Programs

The steps in **Figure 2.8** are adapted to specific language in the MS4 General Permit. However, many of the steps are also key components for establishing a successful stormwater management program. National guidance on building an effective post-construction stormwater program, supported by the U.S. EPA, is available from the Center for Watershed Protection. The guidance is accompanied by several downloadable tools to assist MS4s and other localities in developing their stormwater management programs. All of the steps and topics addressed in **Figure 2.8** are included in the guide and associated tools. The guide, *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program* (Hirschman and Kosco, 2008), can be found at:

http://cwp.org/postconstruction/ or
http://www.dep.wv.gov/WWE/Programs/stormwater/MS4/guidance/Pages/default.aspx

Table 2.5 cross-references the specific steps in Figure 2.8 with the chapters and tools in *Managing Stormwater in Your Community* that are relevant to that step.

Table 2.5. Link Between Compliance Steps and Resources in Hirschman and Kosco (2008)

Compliance Procedure Step From Figure 2.8	Relevant Chapter in Hirschman and Kosco (2008) [1]	Relevant Tool from Hirschman and Kosco (2008)
Step 1. Implement Program Through Development Codes & Planning Documents	Chapter 2: Post-Construction Program Development – Assessing Your Program Chapter 3: Land Use Planning as the First BMP: Linking Stormwater to Land Use Chapter 4: Developing a Stormwater Management Approach and Criteria Chapter 5: Developing A Post-Construction Stormwater Ordinance	Tool 1: Post-Construction Stormwater Program Self-Assessment Tool 2: Program and Budget Planning Tool Tool 3: Post-Construction Model Ordinance[2] Tool 4: Codes and Ordinance Worksheet
Steps 2 through 6: • Develop Pre-Application Stormwater Concept Plan • Pre-Application Meeting • Review & Approve Concept Plan • Develop Final Stormwater Management Plan • Review & Approval Final Stormwater Management Plan	Chapter 7: The Stormwater Plan Review Process	Tool 6: Checklists Tool 7: Performance Bond Tool Tool 8: BMP Evaluation Tool (for proprietary devices)

Compliance Procedure Step From Figure 2.8	Relevant Chapter in Hirschman and Kosco (2008) [1]	Relevant Tool from Hirschman and Kosco (2008)
Steps 7 through 9: • Construct Post-Construction BMPs • Inspect & Verify Post-Construction BMPs • Develop & Submit As-Builts	Chapter 8: Inspection of Permanent Stormwater BMPs During Construction	Tool 6: Checklists Tool 7: Performance Bond Tool
Step 10. Inventory of BMPs, Tracking, Reporting	Chapter 9: Developing a Maintenance Program Chapter 10: Tracking, Monitoring, and Evaluation	Tool 6: Checklists

[1] Hirschman, D. and Kosco, J. 2008. ***Managing Stormwater in Your Community: A Guide for Building An Effective Post-Construction Program.*** *EPA Publication No: 833-R-08-001. http://cwp.org/postconstruction/*

[2] The Post-Construction Model Ordinance tool from Hirschman and Kosco (2008) is a general, national model ordinance. There are useful components in the model ordinance for West Virginia localities. However, West Virginia MS4s (and other local governments wishing to develop a local stormwater program) should incorporate elements from the MS4 General Permit to ensure compliance with the specific MS4 General Permit requirements.

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Chapter 3. Best Management Practice Selection and Design Methodology

What's in This Chapter

Section 3.1 Introduction: Provides an introduction to Treatment Objectives and Performance Goals of stormwater management in West Virginia.

Section 3.2 Stormwater Treatment Capabilities: Introduces the accepted stormwater best management practices (BMPs) and their performance capabilities as documented and implemented using the Runoff Reduction Method.

Section 3.3 BMP Selection: Offers a variety of screening factors that help the designer to select the most appropriate BMP strategy based on the specific site conditions.

Section 3.4 BMP Design: Provides a general overview of the Runoff Reduction BMP design process, including the computational procedures for determining the Target Treatment Volume (Tv).

Chapter 3. Best Management Practice Selection and Design Methodology

3.1 Introduction

The selection, location, and design of an appropriate stormwater BMPs for a given development project will be based on factors related to the ability of the BMP to meet the required stormwater Treatment Objectives and Performance Goals of the development project, various site characteristics that influence the applicability and performance of the BMPs, and the designer's best professional judgment in evaluating the most effective implementation strategy.

Stormwater ***Treatment Objectives*** include (but may not be limited to) managing or reducing runoff volume (as required by the MS4 General Permit) and peak rate of discharge, removal pollutants such as nutrients (Total Nitrogen – TN, Total Phosphorus – TP), Total Suspended Solids (TSS), pathogens, metals, polycyclic aromatic hydrocarbons (PAHs), and thermal impacts. These objectives are generally established by state or local permits, watershed strategies related to the presence of sensitive aquatic resources, or as identified by a water body's Total Maximum Daily Loads (TMDLs).

The level to which these treatment objectives are to be managed or reduced is referred to as the ***Performance Goal***. Example performance goals include maintaining the pre-developed peak rate of runoff from the site; limiting the annual load of a particular pollutant (such as TP) that leaves the development site to a pre-determined or pre-developed level, measured in units of pounds per year (lb/ yr), or other measure of performance. In the case of the MS4 General Permit, the Treatment Objective is to manage the volume of runoff from developed areas, and the Performance Goal is to replicate pre-development hydrologic response.

The specific compliance criterion for the applicable Treatment Objectives and Performance Goals are typically spelled out in the local ordinance, state or federal permit, watershed plan (such as a TMDL Watershed Implementation Plan) or other appropriate governing document. The Performance Goal has been further defined by the MS4 General Permit: manage the runoff volume from a one-inch rainfall event – this volume is referred to as the *Treatment Volume (Tv)*. Guidance documents, including this manual, provide structural and non-structural BMPs that have been evaluated and determined to meet the criterion.

BMPs are generally designed to meet a primary design objective. The selected BMP may also be effective to an extent in addressing multiple Treatment Objectives. However, the BMP design must specifically incorporate provisions for those multiple objectives in order to be successful. Therefore, it is important for the designer to understand both the Treatment Objectives and the capabilities of the available BMPs in order to select and design the most effective BMP strategy.

3.2. Stormwater Treatment Capabilities

This section provides the background for designers to understand how the different BMPs perform and the different design adaptations that can improve the BMP's capability to achieve any one or multiple Performance Goals. This includes a description of the Treatment Objectives and the basic pollutant removal pathways of the BMPs.

3.2.1. Overview of the BMPs

West Virginia's approved BMPs are listed here using the **Chapter 4** section designations from the detailed design specifications. **Chapter 1** provides a pictorial introduction and a brief description of each BMP and a basic summary of the design features.

4.2.1 Sheet Flow to Vegetated Filter Strips and Conservation Areas
4.2.2. Impervious Surface Disconnection
- Simple disconnection
- Simple disconnection with soil amendments
- Disconnection with compensatory practices

4.2.3. Bioretention
- Traditional (main chapter)
- Water Quality Swale (Supplement A)
- Urban Bioretention (Supplement B)
- Residential Rain Garden (Supplement C)

4.2.4. Permeable Pavements (permeable interlocking concrete pavers, pervious concrete, porous asphalt, concrete grid pavers)
4.2.5. Grass Swales
4.2.6. Infiltration (dry wells, infiltration trenches, infiltration basins)
4.2.7. Regenerative Stormwater Conveyance System
4.2.8. Rainwater Harvesting (cisterns and rain tanks)
4.2.9. Vegetated Roofs (intensive and extensive)
4.2.10. Filtration (surface sand filters, underground sand filters, perimeter sand filters) – water quality credit only (no runoff reduction performance))
4.2.11. Stormwater Wetlands (subsurface gravel wetlands, wetland basins, multi-cell wetland or pond/wetland combination) – water quality credit only (no runoff reduction performance)

Some Stormwater Ponds Are Not Assigned Runoff Reduction Performance Values

Specifications for Dry Extended Detention Ponds and Wet Ponds are not included in this manual since they are not credited with any Runoff Reduction benefits. However, they can be utilized for other stormwater treatment objectives, such as peak rate control for downstream flood protection.

3.2.2. The Runoff Reduction Method

The Runoff Reduction Method is a three-step design process for implementing structural and nonstructural stormwater BMPs that address the impacts of land development and conversions on the downstream aquatic resources by:

1. Reducing the increase in runoff volumes by minimizing impervious cover and mass grading, and maximizing the retention of forest cover, natural areas, and undisturbed soils (especially those soils that are conducive to landscape infiltration);
2. Applying BMPs individually or in series that have been demonstrated to reduce runoff volumes through infiltration, evapotranspiration, extended filtration, and attenuation; and
3. mplementing additional BMPs to address as needed any remaining volume of runoff, peak rates of discharge, and/or pollutant load reductions.

The use of Better Site Design practices to achieve **Step 1** is covered in detail in **Section 4.1**. The selection of applicable BMPs to achieve **Steps 2** and **3** are discussed in **Section 3.4** of this Chapter.

Runoff Reduction

The MS4 General Permit requires that the increased volume of runoff from urban development be managed on site so as to mimic the natural or pre-developed hydrology. Pre-developed hydrology in the general terms of permit compliance is independent of site specific characteristics and is defined as the natural conditions where runoff from approximately 90% of the annual rainfall is either infiltrated, taken up by plants, or conveyed by shallow subsurface flow (or interflow) to streams and rivers. Nearly all of the remaining rainfall becomes surface runoff conveyed to receiving waters (FISRWG, 1998).

Analysis of precipitation data for West Virginia indicates that 90% of the annual rainfall events are one (1) inch or less. **Therefore, the BMP *Performance Goal* is to manage on-site the runoff from a one-inch rainfall event in order to reasonably mimic natural hydrologic processes**. **Section 3.4** of this chapter provides a description of the calculation procedures for determining the volume of runoff from the one-inch event, referred to as the Treatment Volume (*Tv*).

Since the specific characteristics of the landscape such as soils and slopes, determine the path by which runoff leaves the site in the pre-developed condition, the designer must select an appropriate BMP strategy that is compatible with those characteristics and will therefore mimic those pre-developed pathways. Where pre-developed conditions include permeable soils, BMPs can be designed to effectively mimic infiltration by establishing or preserving adequate ponding (attenuation) volume and surface area of permeable soils in one or multiple locations within the development site. Where the existing soils (Hydrologic Soil Groups C and D) or developed site conditions (such as the extent of earthwork cut and/or fill) preclude the use of Infiltration, other practices can be designed to mimic the attenuation and slow release of runoff by establishing a ponding area, a depth of engineered soil media, and an underdrain. This discharge condition is similar to the shallow subsurface interflow that is common in areas with low soil permeability.

Better Site Design and Runoff Reduction

In almost all cases, BMP performance can be enhanced by providing a vegetative component to improve the evapotranspiration characteristics of the developed site. Section 4.1 discusses the important and effective strategy of minimizing the increase in runoff volume through Better Site Design strategies, thereby reducing the extent to which designers must rely on structural BMPs to achieve the volume reduction Performance Goal.

Pollutant Removal

The MS4 General Permit puts a premium on achieving runoff volume reduction at a development site as a measure of compliance with the goal of protecting downstream resources. This incorporates the beneficial effects of reducing frequency and peak rates of discharge for certain storm events with the additional benefit of reducing pollutant loads. Runoff volume is the first of two important factors in determining the runoff pollutant load; the second being the concentration of the targeted pollutant, usually measured in milligrams per liter (mg/l) or other appropriate units. The computed annual load reported in terms of pounds per year (lbs/yr) is the product of the annual runoff volume multiplied by the typical pollutant concentration. Therefore reducing one or both of these factors will result in a reduced annual load. **Section 3.4** provides a description of the computations used to calculate the pollutant loads associated with the target Tv.

Annual Values for Runoff and Pollutant Concentrations

The runoff volume reduction criteria specifically address the reduction of runoff associated with an "annual" rainfall distribution in order to simplify the computational procedures as well as the variability associated seasonal and daily rainfall patterns. Similarly, the concentration of pollutants can often vary on a seasonal basis or even over the course of a single rain event (based on rainfall intensity, pollutant washoff, etc.) and is therefore measured using a single "event mean concentration" (EMC). The EMC reflects an average pollutant concentration in urban stormwater runoff derived over many storm events and in many different locations. The computed load reduction is therefore considered to be an "annual reduction" and not a single event modeled reduction.

Components of Total Pollutant Load Reduction

The ability of BMPs to reduce the annual runoff volume either through infiltration, evapotranspiration, reuse, or extended filtration is referred to as the ***Runoff Reduction*** capability, and is expressed as a percent removal of the runoff associated with the 90th percentile rain event. The ability of BMPs to reduce annual pollutant loads by reducing the EMC of the particular pollutant(s) is referred to as the ***Pollutant Removal*** capability and is expressed as a percent removal of the annual pollutant load calculated using the Simple Method. The total annual load reduction is referred to as ***Total Pollutant Load Reduction***. **Table 3.4** provides the accepted Runoff Reduction values for the BMPs, and **Table H.2** in **Appendix H** includes the accepted Pollutant Removal and Total Pollutant Load Reduction.

Level 1 and Level 2 BMPs

Each BMP has a different Runoff Reduction capability, as well as a different Pollutant Removal capability. Some BMPs may achieve reductions solely through Pollutant Removal performance and provide no Runoff Reduction, while others may provide only Runoff Reduction and no measureable Pollutant Removal, and finally, some are able to achieve both. To further improve on any given BMP's performance, the designer may choose to improve on the "standard" design features of a Level 1 design by upgrading to the "enhanced" design features of a Level 2 design.

The basis of the Level 1 and Level 2 design format is a thorough evaluation of BMP performance literature. BMP design factors that enhance nutrient pollutant removal and runoff reduction were isolated. Standard design features that should be included in all designs (i.e., not directly related to differential nutrient removal or runoff reduction rates) were identified. These include any features needed to maintain proper and safe function of the BMP.

Next, prior research into BMP adaptations for the purposes of urban retrofitting was utilized to identify and isolate additional design features and their influence on performance. These combined efforts helped to accurately identify critical design features that could be enhanced to improve performance in terms of both Pollutant Removal and Runoff Reduction, as well as the expected relative improvement in performance that could be expected. The result is the Level 1 and Level 2 design criteria and performance credits.

The standard Level 1 design features typically include the following:

- Key safety features;
- Aesthetics;
- Safe conveyance of larger storms;
- Operational longevity (design with maintenance in mind); and
- Standard site feasibility constraints.

The Level 2 enhanced features typically include:

- Providing a larger storage component within the BMP;
- Improving design geometry and hydraulics to increase the length of the flow path and residence time within the BMP;
- ncreasing the surface area and variety of vegetative cover within the BMP to improve evapotranspiration and pollutant uptake; and
- Providing additional runoff reduction and/or pollutant removal pathways to the BMP, such as adding soil amendments to a grass swale (thereby adding enhanced features for infiltration and attenuation to the standard feature of settling).

Table 3.1 describes the Bioretention design Levels as an example of the different criteria typically associated with Level 1 and Level 2. These Level 1 and Level 2 design features are outlined in detail within the design specifications in **Chapter 4**. It is important to note that some BMPs in **Chapter 4** have only one design level (e.g., Infiltration, Rainwater Harvesting). This is because the sizing and design guidance and the resulting runoff reduction performance are more straight-forward and not conducive to the design level approach.

Table 3.1. Bioretention Design Levels: Descriptions & Performance

Design Level	Description	Applications	Performance Achieved Towards Reducing 1" of Rainfall
Level 1	Basic Design -- Underdrain At least 1.5 feet of soil media depth, but less than 2.0 feet No infiltration sump below underdrain pipe(s)	Sites with vertical constraints such as high bedrock or water table OR confirmed karst, stormwater hotspot, or other applications that require an impermeable liner.	60% volume reduction for the Design Volume of the practice[1]
Level 2	Infiltration Design – No underdrain, water infiltrates into the underlying soil within 48 hours. OR Extended Filtration Design – • Underdrain • At least 2.0 feet of soil media depth, OR • At least 1.5 feet of soil media depth with stone sump below underdrain designed to drain design volume within 48 hours on suitable soils (e.g., limited on fill).	Generally most sites that have good to marginal infiltration rates -- Hydrologic Soil Groups (HSGs) A, B, and C and do not require an impermeable liner. Use the Infiltration Design for tested infiltration rates > 0.5 inches per hour, and the Extended Filtration Design for other sites.	100% volume reduction for the Design Volume of the practice1

[1] *Design Volume includes storage on the surface, within the soil media, and in the infiltration sump. The Design Volume can be 100% of that needed to meet the 1-inch performance standard OR some proportion of it when used in conjunction with other practices.*

Peak Rate Control

Designers may also be required to design stormwater practices to provide peak rate control for larger storms for downstream channel protection and/or flood control. In West Virginia, this is likely to be a local stormwater standard or requirement. The Runoff Reduction Method allows for the annual Runoff Reduction credit to be applied to the large storm computations to possibly reduce the detention storage volume required to control the larger design storm events. This is achieved through a curve number adjustment for the contributing drainage area (CDA): the annual Runoff Reduction credit is converted from cubic feet or acre-feet to watershed-inches of retention storage and used to "back calculate" an adjusted (reduced) curve number using the TR-55 Runoff Equations (USDA, 1986). This new curve number can then used when computing the large storm peak discharge and storage volume needed to meet downstream channel or flood protection requirements. This computational procedure is discussed in more detail in **Section 3.4.4** of this Chapter.

Adjusted Curve Numbers Vary by Storm Event

An adjusted curve number must be computed for each storm event (e.g., 2-year, 10-year, etc.) due to the diminishing effect of the retention storage on increasing rainfall depths.

If the BMP has a storage component that can be expanded in order to provide a greater volume of storage than required by the Level 1 or Level 2 criteria, the designer may increase those components (as allowed by the BMP design specifications) and increase the large storm benefits. The designer may also choose to route the design storm through the available storage (taking into account the retention and slow drawdown characteristics of the Runoff Reduction BMP) using a storage-indication method routing model rather than compute an adjusted curve number.

It is very important for designers to understand the difference between the "annual" runoff volume credit and a single event modeled peak rate of discharge. The reduced curve number may not be appropriate for the sizing of downstream drainage infrastructure. In all cases, the designer should evaluate the stormwater management requirements and verify the appropriate hydrologic design methods.

Table 3.2 provides a general comparative summary of the basic Treatment Objective capabilities of the different BMPs.

The combined performance of Runoff Reduction and Pollutant Removal, in conjunction with the Level 1 and Level 2 design, is the foundation of the Runoff Reduction Method. The technical support for the credited performance of the BMPs can be found in Hirschman et al. (2008), and consists of extensive reviews of BMP performance monitoring studies incorporated into the National Pollutant Removal Performance Database (CWP, 2007). Estimates for some BMPs should be considered provisional (e.g., filter strips) due to limited data. Estimates for new practices as well as updates to existing practices will be provided as supported by ongoing research. (Refer to **Section 3.2.4** for the process of developing and approving new performance credits, design criteria, and BMPs.)

Table 3.2. Comparative Overall Performance Capability of BMPs

BMP		Runoff Reduction[1]	Pollutant Removal[1]	Total Pollutant Load Reduction	Peak Rate Control
Sheet Flow to Vegetated Filter Strips		YES	NO	PARTIAL[2]	PARTIAL[5]
Simple Disconnection		YES	NO	PARTIAL[2]	PARTIAL[5]
Simple Disconnection with Compensatory Practices	Micro-Infiltration	YES	YES	YES	PARTIAL to FULL[6]
	Residential Rain Garden	YES	YES	YES	PARTIAL to FULL[6]
	Rainwater Harvesting	YES	YES	YES	PARTIAL[6]
	Urban Bioretention	YES	YES	YES	PARTIAL[6]
Bioretention		YES	YES	YES[3]	PARTIAL to FULL[6]
Permeable Pavement		YES	YES	YES[3]	PARTIAL to FULL[6]
Grass Swales		YES	YES	YES[3]	PARTIAL[5]
Infiltration		YES	YES	YES[3]	PARTIAL to FULL[6]
Regenerative Stormwater Conveyance System		YES	YES	YES	PARTIAL to FULL[6]
Rainwater Harvesting		YES	NO	PARTIAL[2]	PARTIAL[6]
Vegetative Roofs		YES	NO	PARTIAL[2]	PARTIAL[5]
Filtration		NO	YES	PARTIAL[4]	NONE
Stormwater Wetlands		NO	YES	PARTIAL[4]	PARTIAL[7]

[1] *The* Runoff Reduction *and/or* Pollutant Removal *can be improved by upgrading the design from Level 1 to Level 2. Refer to* Section 3.2.2.

[2] *Total Pollutant Load Reduction is a function of* Runoff Reduction *only.*

[3] **Total** *Pollutant Load Reduction is a function of* Runoff Reduction *and* Pollutant Removal.

[4] *Total Pollutant Load Reduction is a function of* Pollutant Removal *only.*

[5] *Adjustment to CDA curve number & time of concentration.*

[6] *Adjustment to CDA curve number & time of concentration, and additional storage volume.*

[7] *Limited ponding depth allowed above the wetland normal pool.*

Pollutant Removal Processes

At most sites, designers may need to employ several practices in a "roof to stream" sequence in order to meet the criteria of managing the Tv runoff reduction targets (e.g., rooftop disconnection drains to front yard bioretention, which then drains to a dry swale, and then to a constructed wetland). These "treatment trains" are effective in sequentially reducing runoff volumes through each BMP. Pollutant Removal, on the other hand, is limited since the available pollutant load, i.e. the fraction of the targeted pollutant that is physically able to be removed by the particular pollutant removal processes or pathways in the BMP, is finite. Therefore, there is an upper limit to the pollutant removal performance of any given BMP or series of BMPs.

This upper limit on Pollutant Removal highlights a significant benefit of utilizing and accounting for the Runoff Reduction component of the BMPs. Runoff Reduction is a function of combining flow attenuation with i) infiltration into existing soils, ii) evapotranspiration through the soil and vegetation interface, iii) alternative uses such as irrigation or internal non-potable water demand, and iv) extended filtration to mimic the flow path of runoff in areas with tight or low-permeable soils. The cumulative Runoff Reduction benefit of these design features is not limited by a removal process or the form of a targeted pollutant, allowing multiple Runoff Reduction BMPs in series to achieve a very high performance goal through Runoff Reduction rather than Pollutant Removal.

It should be noted that extended filtration in an undeveloped watershed also incorporates the natural processes of infiltration and evapotranspiration; however, concentrating runoff from a developed drainage area to a small footprint (relative to the drainage area) limits the capability of these natural processes, especially when also confronted with less than favorable soil conditions. Extended filtration BMPs provide an engineered soil media to overcome the limitations common on development sites (disturbed soil profiles, limited space for dispersing runoff, etc.).

Becoming familiar with the performance characteristics of the BMPs will help the designer meet the challenges of typical and atypical development sites. **Table 3.3** provides a brief overview of the more common physical, chemical, and biological processes by which the BMPs remove pollutants.

Table 3.3. Stormwater Pollutant Removal Processes

Removal Process	Description and Pollutants Affected	BMPs
Gravitational Separation (also settling or sedimentation)	**Definition**: Downward removal of solids denser than water, and floatation removal of those lighter than water. **Pollutants**: sediment, solids (particulates associated with other pollutants such as nutrients and metals), oil (hydrocarbons), BOD, particulate COD	Cisterns, Permeable Pavement, Grass Swale, BMPs with ponding component, Bioretention, Regenerative Stormwater Conveyance System, Filtration, Stormwater Wetlands, and Wet and Dry Extended Detention Ponds
Filtering	**Definition:** Straining of pollutants by passing stormwater through a media finer than the target pollutants. **Pollutants**: solids, pathogens, particulate nutrients, particulate metals, BOD, particulate COD	Filtration, Vegetated Filter Strips, Bioretention, Permeable Pavement, Grass Swale, Regenerative Stormwater Conveyance System, Vegetated Roof, Stormwater Wetlands.

Removal Process	Description and Pollutants Affected	BMPs
Infiltration	**Definition:** passing stormwater downward through existing soils below the surface grade **Pollutants**: volume, solids, pathogens, nutrients, metals, organics, BOD, particulate COD	Infiltration, Vegetated Filter Strips, Bioretention, Permeable Pavement, Grass Swale, Regenerative Stormwater Conveyance System,
Sorption	**Definition**: Includes Adsorption and Absorption – the physical molecular level attraction of a pollutant to media or soil particles. No chemical change (such as ion exchange occurs). **Pollutants**: dissolved phosphorus, metals, and organics.	Filtration, Vegetated Filter Strips, Bioretention, Permeable Pavement, Grass Swale, Regenerative Stormwater Conveyance System, Vegetated Roof, Stormwater Wetlands.
Biological Uptake	**Definition**: Broadly termed transfer of substances from runoff to plants; can include evapotranspiration. **Pollutants**: volume, hydrocarbons, nutrients, metals, organics, BOD, particulate COD	Vegetated Filter Strips, Bioretention, Grass Swale, Vegetated Roof, Stormwater Wetlands
Ion Exchange	**Definition**: Molecular exchange of one ion from the soil or filter media with an ion in the stormwater to remove pollutants; the ion from the media passes harmlessly through with the stormwater, while the pollutant remains sequestered in the media. **Pollutants**: metals	Filtration (depending on the media)
Chemical Transformation	**Definition:** Process by which pollutants react with other compounds to change structure and are either harmlessly removed or sequestered. **Pollutants:** nitrogen (ammonia, nitrate, nitrite), organics, hydrocarbons	Filtration, Vegetated Filter Strips, Bioretention, Permeable Pavement, Grass Swale, Regenerative Stormwater Conveyance System, Vegetated Roof, Stormwater Wetlands.

3.2.3. BMP Runoff Reduction Credits

Table 3.4 provides the comparative runoff reduction credits of the BMPs covered in this manual. These BMPs also have corresponding pollutant removal credits for TN, TP, and TSS for compliance with requirements in the Chesapeake Bay watershed, as well as other parameters that may be required in watersheds designated as impaired. **Appendix H** provides an expanded version of **Table 3.4** to include these other credits.

Table 3.4. Comparative Runoff Reduction Credit of BMPs

Best Management Practice		Runoff Reduction Credit[1,2] (%)
Sheet Flow to Vegetated Filter Strips[2]	A/B Soils	50 (.06ft^3/ft^2)
	C/D Soils	25 (.03ft^3/ft^2)
	C/D Soils w/ compost amended soils (CA) (See Appendix D)	50 (.06ft^3/ft^2)
Sheet Flow to Conservation Area[2]	A/B Soils	75 (.09ft^3/ft^2)
	C/D Soils	50 (.04ft^3/ft^2)
Simple Disconnection[2]	A/B Soils	50 (.04ft^3/ft^2)
	C/D Soils	25 (.02ft^3/ft^2)
	C/D Soils w/ CA (Appendix D)	50 (.04ft^3/ft^2)
Simple Disconnection with Compensatory Practices	Micro Infiltration	Refer to Infiltration
	Residential Rain Garden	Refer to Bioretention Level 1 and Level 2
	Rainwater Harvesting	Refer to Rainwater Harvesting
	Urban Bioretention	40
Bioretention	Level 1	60
	Level 2	100
Permeable Pavement	Level 1	45
	Level 2	100

Best Management Practice		Runoff Reduction Credit[1,2] (%)
Grass Swale	A/B Soils	20
	C/D Soils	10
	C/D w/ CA	20
Infiltration		100
Regenerative Stormwater Conveyance System[3]	A/B Soils	100
	C/D/Soils	60
Rainwater Harvesting		90[4]
Vegetative Roof		100
Filtration	Level 1	0
	Level 2	0
Stormwater Wetlands	Level 1	0
	Level 2	0
Dry Extended Detention	Level 1	0
	Level 2	15
Wet Pond	Level 1	0
	Level 2	0

[1]Runoff Reduction expressed as a percent reduction in the annual volume of runoff from rain events up to 1" (Hirschman et al., 2008) based on the BMP design as prescribed in Chapter 4 of this manual
[2] Runoff Reduction values for sheet flow and simple disconnection practices are based on a ft^3 credit per ft^2 of BMP surface area (refer to Section 3.4 for details).
[3] New practice – performance credits comparable to bioretention/amended media filter. Credit is 100% of provided storage in step pools.
[4]Runoff Reduction credit is variable up to 90% - based upon storage and water usage budget.

3.2.4. New BMPs and Updated Design Criteria

Over the last 10 years, as new stormwater programs have been adopted by state and local governments, numerous products have been developed to help designers and regulators easily address requirements on new and redevelopment sites. The process of introducing new proprietary and public domain stormwater treatment technologies has been very inconsistent nationwide.

The rapid pace of new stormwater treatment product development by manufacturers has created a complex regulatory hurdle for accepting and assigning an appropriate performance credit (e.g., pollutant removal) to new technologies. Some states implement a performance review process while others simply accept the professional responsibility of the licensed engineer as having evaluated the accuracy of the various performance claims. As more products are placed in service, it becomes very evident whether a particular product actually works, and will work for the desired operational life cycle (usually assumed to be at least one year of typical rainfall). The result has been for many jurisdictions to arbitrarily disallow or limit the number of proprietary products, both good and bad.

The introduction of new public domain practices, including design changes, has been much more paced since they have typically been introduced concurrent with a two or three-year research project with unofficial preliminary results setting the stage for gradual acceptance and further research. In recent years, several studies on stormwater BMPs have been completed in NC, MD, PA, NH, and other states. Research in New Hampshire at the University of New Hampshire Stormwater Center is especially relevant to West Virginia given the cold weather testing being conducted.

The intent of this guidance manual is to capture the latest research and design guidelines. However, even as this manual is written, experts are researching more improvements that may boost the performance or decrease the costs, or both, of stormwater BMPs. Therefore, the West Virginia Department of Environmental Protection (WVDEP) will implement official updates to this guidance manual as necessary.

In West Virginia, new products will be reviewed on a case by case basis until such time that a more formal performance evaluation protocol is established and adopted at WVDEP, perhaps in conjunction with or based upon similar protocols in other states (e.g., Virginia, New Jersey).

Chapter 3. Best Management Practice Selection and Design Methodology

3.3. BMP Selection

The selection of appropriate BMPs for any given development project is based on a review of the available BMPs, the different performance and design characteristics, and most importantly, best professional judgment. The process outlined here is a suggested chronology of selecting, locating, and designing BMPs for new and redevelopment projects and builds upon the three-step Runoff Reduction Method design process introduced in **Section 3.2.2**.

This Runoff Reduction Method design process is based on the presumption that the designer has already identified the specific Treatment Objectives and Performance Goals for the project. This is important because it will provide the foundation on which to evaluate the relative benefits of different Runoff Reduction Method strategies such as Better Site Design and/ or structural Runoff Reduction BMPs.

The process of identifying the specific Treatment Objectives and Performance Goals for the project should have also included an assessment of whether any Incentive Standards can apply to the particular project. Incentive Standards include a reduced volume reduction Performance Goal for any of the following development types:

a) Redevelopment;
b) Brownfield redevelopment;
c) High density (>7 units per acre);
d) Vertical density, (floor to area ratio of 2 or >18 units per acre);
e) Mixed use and transit oriented development (within ½ mile of transit)

Runoff Reduction Method Step 1: Reduce the increase in runoff volumes by minimizing impervious cover and mass grading, and maximizing the retention of existing vegetation, forest cover, natural areas, and undisturbed soils (especially those soils that are conducive to landscape infiltration).

The design strategies for this step, generally referred to as Better Site Design, are presented in **Chapter 4.1**. The process of evaluating and maximizing the implementation of these site design strategies as a first step is critical in selecting appropriate BMPs since it has the potential to dramatically reduce the target Tv; the designer may be able to select BMPs with a smaller footprint or lower Runoff Reduction credit.

First Step: Better Site Design

The evaluation and implementation of Better Site Design strategies as outlined in Chapter 4.1 should be the first step of this process as it will likely reduce the Tv required and therefore influence the selection of the most effective BMP(s).

Runoff Reduction Method Step 2: Apply BMPs individually or in series that have been demonstrated to reduce runoff volumes through infiltration, evapotranspiration, extended filtration, and attenuation.

The Runoff Reduction Method Step 2 involves the process of screening the different BMPs based on their performance capabilities and the feasibility factors associated with the project site. This includes assessing the Treatment Objectives and Performance Goals of the project (**Tables 3.2** and **3.4**), land use factors (**Table 3.5**), site characteristics and feasibility (**Table 3.6**), water resource settings (**Table 3.7**), and community acceptance (**Table 3.8**).

The first screening is a review of potential BMPs in terms of the Treatment Objectives and Performance Goals and is presented in **Table 3.2** and **Table 3.4.** The designer should assess the ability of the BMP to meet any of the following Treatment Objectives as may be required:

Treatment Objectives:

- Runoff Reduction (MS4 General Permit compliance)
- Pollutant Removal (Chesapeake Bay or local TMDLs)
  - o Nutrients (TP, TN)
  - o Sediment (TSS)
- Peak Rate Control (most likely local stormwater requirements)
  - o Channel Protection
  - o Flood Protection
- Other watershed specific objectives:
  - o Temperature
  - o Pathogens
  - o Metals

Once the designer has established the "short list" of BMPs that will adequately address the Treatment Objectives, the next step is to ensure the applicability to the given site characteristics and future land uses. The tables provided in **Sections 3.3.1** through **3.3.4** provide a general level of screening for each BMP. Designers will gradually gain experience in the performance capabilities of the practices and how they fit into the different site conditions so as to select the most appropriate BMP or combinations of BMPs.

After the BMPs have been screened and the most appropriate BMPs have been selected, the designer will move to Step 3 of the Runoff Reduction Method:

Runoff Reduction Method Step 3: Evaluate the overall performance of the selected BMPs in reducing the target Tv and pollutant loads, and apply additional Runoff Reduction or Pollutant Removal BMPs as needed.

Step 3 is covered in detail along with the computations for the Tv and annual pollutant loads in **Section 3.4**.

3.3.1. Land Use

The first and most basic screening factor is the proposed land use which is to be served by the BMP. Definitions and explanations of the land use categories in **Table 3.5** are as follows:

Rural: Impervious cover within rural land use (generally considered residential lots > 1/3 acre) is generally widely dispersed. And while the acreage of managed turf can be significant, there is usually adequate space to implement any number of low cost, low maintenance BMPs.

Rural lands are especially suited for minimization and avoidance strategies, as well as vegetated BMPs such as filter strips, conservation areas, etc.

Residential: This includes medium to high density residential developments (< 1/3 acre lot sizes) that generally have limited space compared to rural land. Also, depending on house size and roadway widths, BMPs are likely to be located in close proximity to residences where public safety, nuisance insects, and maintenance are common concerns related to stormwater control measures.

Roads and Highways: Roads and highways typically generate high stormwater pollutant loads due to vehicle traffic and winter deicing activities. Project specific limitations on placement of BMPs related to traffic safety, large storm conveyance, and available space for adequate pre-treatment will typically limit application.

Commercial Development: Commercial development is the most varied land use in terms of project drainage area size, land use, pollutant loads, and other factors. Since commercial development can potentially have available space and is generally a large drainage area under one management, most practices can be recommended. Limitations are based on the potential for drainage areas that are too large, or practices specifically intended for residential areas.

Industrial Development: Industrial development is also highly variable in terms of size and land use. Many industrial facilities are completely covered and do not expose materials or processes to stormwater, thus being more similar to office or business settings. Restrictions on BMPs are generally based on the potential for stormwater "Hotspots," covered in detail in **Chapter 5.**

Table 3.5. BMP Screening: Land Use

BMP	Rural	Residential	Roads & Highways	Commercial	Industrial
Vegetated Filter Strips[1]	Preferred	Preferred	Preferred	Preferred	Limited[2]
Simple Disconnection	Preferred	Preferred	Restricted	Limited[3]	Restricted[3]
Simple Disconnection with Compensatory Practices	Limited[4]	Limited[4]	Restricted	Limited[3]	Restricted[3]
Bioretention	Preferred	Preferred	Preferred	Preferred	Restricted[5]
Permeable Pavement	Limited[6]	Limited[6]	Limited[6]	Preferred	Restricted[5]
Grass Swale	Preferred	Preferred	Preferred	Limited[7]	Limited[7]
Infiltration	Preferred	Preferred	Preferred	Preferred	Restricted[5]
Regenerative Stormwater Conveyance System	Limited	Preferred	Preferred	Preferred	Preferred
Rainwater Harvesting	Preferred	Preferred	NA	Preferred	Preferred
Vegetative Roof	Restricted[8]	Restricted[8]	NA	Preferred	Preferred

BMP	Rural	Residential	Roads & Highways	Commercial	Industrial
Filtration	Limited[9]	Limited[9]	Preferred	Preferred	Preferred
Stormwater Wetlands	Preferred	Preferred	Preferred	Preferred	Preferred

Preferred	– Good application
Limited	– Probably not the best choice due to one of the screening factors, but can be accepted
Restricted	– specific design restrictions based on one of the screening factors

[1]Vegetated Filter Strips include Sheet Flow to Conservation Areas.
[2]May require pretreatment depending on land use and pollutant loading.
[3] Intended for residential or other small impervious areas.
[4] Alternative practices add a maintenance component – should be adequate room for Simple Disconnection
[5] Depending on specific land use – may limit infiltration and require additional maintenance
[6] Maintenance requirements
[7] Drainage area and large storm conveyance. Adjustment to CDA, curve number & time of concentration, and additional storage volume.
[8]Typical residential roof geometry restricts application
[9] Excessive maintenance burden of underground systems in residential areas

3.3.2. Site Characteristics and Feasibility

This screening factor begins the process of correlating the site conditions to the practical design factors for the different BMPs. The designer must identify any physical constraints at the project site that may restrict or preclude the use of a particular BMP. This includes the existing site conditions such as soil types (and depth to limiting layers such as bedrock), as well as the proposed site conditions such as earthwork, available space, and grades (see **Table 3.6**). More detailed site investigations may be required to adequately address some constraints.

The primary factors are as follows:

Soils: The key evaluation factors are based on an initial investigation of the Natural Resources Conservation Service (NRCS) Hydrologic Soil Groups (HSGs) at the site. Knowledge of the soil groups present on the site is also needed for runoff calculations. Note that more detailed geotechnical tests are typically required for infiltration feasibility and during design to confirm other engineering characteristics; however the presence of HSG A or HSG D soils is most likely enough to screen the choice of certain BMPs. Additional information on soils and soil testing is provided in **Appendix B**.

Depth to Water Table: The separation of the BMP and the seasonally high water table is a safety factor intended to protect the water table and the BMP.The debate over the need for greater than one-foot of separation is often based on the presumed margin of error in predicting the actual water table elevation.This distance, measured from the bottom or floor of the BMP can be modified based on the reliability of the investigation.

Depth to Bedrock: Similar to the depth to water table, this factor includes a constructability element that is best predicted before construction. A relatively shallow depth to bedrock may limit practices that require a deep footprint or outlet structure.

Minimum Hydraulic Head:This factor reflects the estimate of the required elevation difference needed to pass runoff through the BMP (from the inflow to the outflow) to allow for gravity operation.

Slope: This reflects the potential effect of slope on the practice. Specifically, the slope guidance refers to how flat the area must be where the practice is installed, and/or the grades of the interior components. In addition, similar considerations can be made for the contributing drainage area; however, steep drainage areas can be addressed with adequate energy dissipation as the flow approaches the practice.

Contributing Drainage Area (CDA): This factor reflects the recommended minimum or maximum drainage area that is considered optimal for a practice. If the CDA present at a site is slightly greater or smaller than that which is recommended, some leeway may be warranted if design considerations address the potential issue and more importantly, the practice meets other management objectives.

Space: This is a very general estimate of the area of BMP footprint as a function of the CDA.

Table 3.6. BMP Screening: Site Characteristics and Feasibility

BMP	Soils[1]		Other Site Constraints[2]					
	HSG A/B	HSG C/D	Depth WT[3]	Depth BR[3]	Min Hyd Head[4]	Max Slope[5]	CDA	Space[6]
Vegetated Filter Strips[7]	Yes	Yes w/ CA[8]	1 to 2ft.	1 to 2 ft.	NA	6%/8%[9]	3 ac.	15to25%
Simple Disconnection	Yes	Yes w/ CA[8]	1 ft.	1 ft.	NA	5%; 1%to2% is best	Max 1,000 sq.ft.	Nominal
Simple Disconnection with Compensatory Practices	Refer to each practice: Bioretention, Infiltration, Rainwater Harvesting, Urban Bioretention.							

BMP	Soils[1]		Other Site Constraints[2]					
	HSG A/B	HSG C/D	Depth WT[3]	Depth BR[3]	Min Hyd Head[4]	Max Slope[5]	CDA	Space[6]
Bioretention	Yes	Yes w/ UD[10]	2 ft.	1 ft.	3to5ft.	1% to 5%	2.5 ac.[11]	4%to6%
Urban Bioretention	NA	NA	NA	NA	3to4ft.	NA	2,500 sq.ft.[12]	Nominal
Permeable Pavement	Yes w/ IR[13]	Yes w/ UD[10]	2 ft.	1 to 2 ft.	2 ft.	1%-3%[14]	2:1 ratio[15]	Nominal
Grass Swale	Yes	Yes w/ CA[16]	1 ft.	1 ft.	2 ft.	4%[17]	5 ac.	3%to5%
Infiltration	Yes w/ IR[13]	NO	2 ft.	2 ft.	2to4ft.	0to5%	2.5ac[18]	1%to4%
Regenerative Stormwater Conveyance System	Yes	Yes	Below pond level	1 to 2 ft.	Varies	10%[21]	10 to 30 ac.	4%to6%
Rainwater Harvesting	NA	NA	NA	NA	Varies	NA	roof only	Nominal
Vegetative Roof	NA	NA	NA	NA	NA	NA	roof only	NA
Filtration	NA	NA	1 ft.	1 ft.	2to8ft.	NA	2to5 ac.[19]	0to3%
Stormwater Wetlands	Yes w/ liner	Yes	Below	2 ft.	2to4ft.	NA	10 to 25[20]	3%

Abbreviations: WT = water table; BR = bedrock; Min Hyd Head = minimum hydraulic head; CDA = contributing drainage area

[1]NRCS HSGs. [2] These are general ranges only. [3] Vertical distance from bottom invert of practice to water table (WT) or bedrock (BR); may be different in karst. [4] Vertical distance from inflow to practice and its bottom invert. [5] Maximum internal slope of the practice. [6] Typical footprint of practice as percent of drainage area. [7]Vegetated Filter Strips include Sheet Flow to Conservation Areas. [8]with compost Soil Amendments. [9] 6% forested, 8% grass. [10]With underdrain. [11] Can be larger in some cases. [12]Upper limit is typically based on practical size of planter box. [13]With adequate measured infiltration rate. [14]Slopes can be broken up with terracing. [15]Ratio of area of "run on" pavement to permeable pavement. [16]Some credit with C/D soils, however Compost Amendments provide a boost. [17]Slopes can be broken up with check dams. [18]Critical design factor is limiting the CDA to Infiltration surface area ratio. [19] 100% impervious. [20] 10 ac. may be feasible if groundwater is intercepted and adequate water balance provided. [21] Steeper systems can be designed by increasing the number and size of cobbles and boulders.

3.3.3. Water Resource Settings

Karst Geology: Karst can be a challenging condition in which to apply stormwater management practices. Karst is a dynamic landscape composed of soluble bedrock that is associated with sinkholes, springs, caves, and a highly irregular soil-rock interface. Active karst is defined as karst features within 50 feet of the surface of the site and poses many challenges to BMP design. BMPs that store runoff can actually promote sinkhole formation that may threaten the integrity of the practice as well as structures on the site. In addition, Karst geology provides rapid pathways for water to travel from the surface to deep groundwater and aquifers, so it is safe to assume that any treated or untreated runoff that is infiltrated can reach a drinking water supply in karst areas. Specific site and BMP design considerations are required in areas of karst geology.

Trout Waters: Trout can serve as an indicator for many aquatic organisms that are affected by water temperature. Many aquatic organisms, such as fish and insects, are *ectotherms*, meaning their body temperatures are regulated by their surroundings. Increased water temperatures can lead to behavioral changes, such as increased feeding or aggressiveness, as well as physiological changes, such as increased metabolism or loss of motor function. Fish, especially trout, possess some of the most stringent temperature requirements. Most trout prefer water temperatures between 40 to 70°F, with increased temperatures leading to injury or death.

Especially during the summer months, pavement and rooftop materials capture solar radiation, reaching temperatures much higher than those of natural surfaces. During a storm event, heat is transferred from pavement and rooftops to stormwater runoff, with runoff temperatures at times exceeding 110°F. Runoff at the beginning of a storm often exhibits a temperature spike with temperatures decreasing as rainfall continues and surfaces cool.

Stormwater Hotspots: The ability of BMPs to effectively treat runoff from designated stormwater hotspots varies with the specific land uses and related pollutants and pollutant loads. Generally, hotspots are considered to generate pollutants or concentrations of pollutants that are beyond the performance capacity of traditional stormwater BMPs. Therefore, BMPs that receive hotspot runoff may have design restrictions. Proprietary products, such as oil/water coalescing chambers for fuel handling areas, may be available that can serve to reduce the potential impact. In addition, the entire site may not necessarily be a hotspot; individual activities on the site may be identified as *stormwater hotspot sources areas* and isolated with BMPs that target the particular pollutant. **Chapter 5** contains more detailed information on stormwater hotspots.

Ultra-Urban Sites: This screening factor includes multiple design considerations: high density of people, limited space, high value land, impacted or disturbed soil profiles, pre-set drainage infrastructure, and a wide range of potential urban pollutants. BMPs appropriate for ultra-urban sites are also frequently used at redevelopment and infill sites and to retrofit existing urban development.

See Table 3.7 for a summary of BMPs and water resources settings.

Table 3.7. BMP Screening: Water Resource Settings

BMP	Karst Terrain[1]	Trout Waters[2]	Ultra Urban[3]	Hotspots[4]	Cold Climate
Vegetated Filter Strips[5]	Preferred	Preferred	Restricted	Restricted	Preferred
Simple Disconnection	Preferred	Preferred	Restricted	Accepted[6]	Accepted
Simple Disconnection with Compensatory Practices	Refer to Individual Practices: Bioretention, infiltration, Rainwater Harvesting, Urban Planter.				
Bioretention	SS: Acc LS: Rest.	Preferred	Preferred	Accepted	Preferred
Urban Bioretention	Preferred	Preferred	Preferred	Accepted	Preferred
Permeable Pavement	Preferred	Preferred	Preferred	Prohibited	Preferred
Grass Swale	Accepted	Accepted	Restricted	Restricted	Accepted
Infiltration	SS: Acc LS: Pro	Preferred	Restricted	Prohibited	Accepted
Regenerative Stormwater Conveyance System					
Rainwater Harvesting	Preferred	Preferred	Preferred	Accepted	Accepted
Vegetative Roof	Preferred	Preferred	Preferred	Preferred	Accepted
Filtration	Preferred	Accepted	Preferred	Preferred	Accepted
Stormwater Wetlands	Accepted	Accepted	Restricted	Restricted	Accepted

Preferred	– Widely feasible and recommended
Accepted	--Can work depending on site conditions
Restricted	– Extremely limited feasibility
Prohibited	– Do not use due to limited feasibility and environmental risk

[1] CSN (2009); [2] NCSU (2007); [3] CSN 2011; [4] CWP (2005); **[5]** *Vegetated Filter Strips include Sheet Flow to Conservation Areas.*
[6]Impervious Surface Disconnection.
SS: Small scale application
LS: Large scale application

3.4 BMP Design Methods

The design of stormwater BMPs to manage a volume of runoff can be grouped into two categories: those that utilize a designed storage volume component as the primary mechanism for managing the Tv; and those that utilize the designated treatment surface area of the practice to manage the Tv. Many BMPs depend on both these features for performance; however, the primary sizing and design process typically focuses on one or the other.

Therefore, in order for the designer to select the most effective BMP(s) (**Runoff Reduction Method Step 2**), and evaluate the BMP selection's performance in terms of managing the runoff volume from the 1-inch rainfall event and, when necessary, reducing the targeted pollutant load (**Runoff Reduction Method Step 3**), the designer must first establish the *Tv*.

3.4.1. Target Treatment Volume and Design Volume

The Tv is established by the MS4 General Permit as the volume of runoff from the one inch rainfall event based on the size and land cover of the CDA as determined by the Design Compliance Spreadsheet (and **Equation 3.1**). The basis for this design standard is to provide a simple implementation standard for protecting the physical, chemical, and biological characteristics of receiving waters. Historic rainfall data supports the characterization that approximately 90% of the rainfall events in West Virginia are one inch or less, and that under natural conditions approximately 10% of the volume of precipitation falling to earth runs off to surface waters via surface/overland flow (FISRWG, 1998). Therefore managing the runoff from this design rain event will reasonably mimic the natural hydrologic process.

The calculation procedure for computing this volume of runoff is as follows:

Equation 3.1

$$Tv = \frac{P \times [(Rv_I \times \%I) + (Rv_T \times \%T) + (Rv_F \times \%F)] \times SA}{12}$$

Where:

- Tv = Target Treatment Volume, in acre-feet (ac.-ft.)
- P = Depth of target rainfall event = one inch
- Rv_I = Volumetric Runoff Coefficient for impervious cover (unit-less)[1]
- $\%I$ = Percent of site in impervious cover (fraction)
- Rv_T = Volumetric Runoff Coefficient for turf cover or disturbed soils (unit-less)[1]
- $\%T$ = Percent of site in turf cover (fraction)
- Rv_F = Volumetric Runoff Coefficient for forest cover (unit-less)[1]
- $\%F$ = Percent of site in forest cover (fraction)
- SA = Total site area, in acres

[1]The Rv coefficients are provided in **Table 3.8** and the land cover definitions are provided in **Table 3.9.**

The Individual BMP Design Volume (Dv) is the volume designed into a particular practice based on sizing criteria as prescribed in each individual BMP specification. The Dv can equal the Tv if there is only one BMP in the CDA. Where multiple BMPs are used as part of a treatment train, the Dv of each individual practice will be part of the overall Tv for the drainage area, with the sum of each BMP's Dv equaling or exceeding the Tv.

Hydrologic Methods

There are numerous methods of modeling the volume and peak flow of stormwater runoff. The NRCS Technical Release 55 (TR55) is the most common for developing runoff hydrographs in order to calculate runoff volume and peak rate of flow. TR55, sometimes referred to as the Curve Number Method, incorporates drainage area characteristics of land cover condition, soil types, and the drainage area time of concentration to predict the rate and volume of runoff resulting from a standard 24-hour rainfall distribution. However, TR55 has been documented to underestimate the runoff from small storm events (VADCR, 1999).

Another common modeling tool is the Rational Method. The Rational Method utilizes a unit-less runoff coefficient and the rainfall intensity, measured in inches per hour, to predict an instantaneous peak rate of runoff. The method was developed specifically for sizing drainage culverts and stormwater conveyance systems to carry the maximum peak rate of runoff from a homogeneous and highly impervious drainage area. The Rational Method does not generate a runoff volume, and while there have been attempts to expand the method's utility by generating a theoretical discharge hydrograph to serve as a BMP design tool, the method is not appropriate for calculating the target Tv.

The Rational Method and the NRCS TR55 are considered single-event design storm methodologies. Another method that is commonly referenced when modeling stormwater runoff is continuous simulation. Continuous simulation models utilize a chronological record of rainfall as input to a rainfall-runoff model (such as NRCS Curve Number methods) to determine the maximum runoff peak rate and total volume. The method will predict the rainfall depth and runoff characteristics for a specific frequency return interval (such as the 90th percentile rainfall event) based on the specific time period of record being evaluated.

These methods all have their strengths and weaknesses. They all require site specific design parameters in order to compute the runoff characteristics. The Runoff Reduction Method calculation for the target Tv as noted above is not necessarily the most accurate; it is independent of the rainfall distribution patterns (rainfall intensity and duration) and the shape of the discharge hydrograph. This means that the entire design Tv may reach the BMP in the first few minutes of an intense storm; or the Tv may slowly enter the BMP over the course of several hours during a steady light rainfall.

As such, the Tv calculation is intended to be a simple and straightforward method for sizing BMPs independent of the obvious variability of rainfall patterns. For this reason, many BMPs have conservative sizing standards for capturing the Tv regardless of storm intensity or peak rate of inflow. These standards include energy dissipation, forebays, and in the case of Bioretention in particular, a minimum requirement for the surface ponding volume.

Volumetric Runoff Coefficient - Rv

The calculation of the Tv is dependent upon knowing the proposed land covers for the site. The Tv calculation provided in **Section 3.4.1** and included in the Design Compliance Spreadsheet contains three general land cover categories: (1) **Impervious Cover**, (2) **Managed Turf** or **Disturbed Soils**, and (3) **Forest/Open Space**.

The negative impact of impervious cover on receiving water bodies has been well documented (CWP 2003, Walsh 2004; Shuster et al. 2005; Bilkovic et al. 2006). More recent research indicates that other land covers, such as disturbed soils and managed turf, also impact stormwater runoff quality and quantity (Law et al, 2008). Numerous studies have documented the impact of grading and construction on the compaction of soils, as measured by increase in bulk density, declines in soil permeability, and increases in the runoff coefficient (OCSCD et al, 2001; Pitt et al, 2002; Schueler, 2000a). As a result, these compacted "pervious" areas have a much greater hydrologic response than is typically predicted in urban runoff models.

Further, highly managed turf can contribute to elevated nutrient loads. Typical turf management activities include mowing, active recreational use, and fertilizer and pesticide applications (Robbins and Birkenholtz, 2003). Research indicates that relatively low impervious cover residential land uses contained significantly higher nutrient concentrations than sites with higher impervious cover (CWP, 2008). This suggests that residential areas with relatively low impervious cover can have disturbed and intensively managed pervious areas that contribute to elevated nutrient levels.

The Runoff Reduction Method Tv computation takes into account impervious cover as well as the other land cover types that have been identified as generating more runoff from the developed site. In addition, this Tv value is utilized in the pollutant load computations (discussed in **Section 3.2.2**).

The runoff coefficients provided in **Table 3.8** were derived from research as outlined in the Runoff Reduction Technical Memorandum (Hirschman et al., 2008).

Table 3.8. Site Cover Volumetric Runoff Coefficients (Rv)

Land Cover	Hydrologic Soil Group			
	A	B	C	D
Forest Cover	.02	.03	.04	.05
Disturbed Soil/ Managed Turf	.15	.20	.22	.25
Impervious Cover	.95	.95	.95	.95

References: Pitt et al (2005), Lichter and Lindsey (1994), Schueler (2000a), Schueler, (2000b), Legg et al (1996), Pitt et al (1999), Schueler (1987) and Cappiella et al (2005).

There can be many points of interpretation about which land covers fall into each of the three categories for any particular site. **Table 3.9** provides guidance on how to assign land covers for each of the categories.

Table 3.9. Land Cover Guidance for Calculating the Design Volume

Impervious Cover
• Roadways, driveways, rooftops, parking lots, sidewalks, and other areas of impervious cover. • Gravel roadways, parking lots, and other gravel surfaces on top of a compacted sub-base. • This category also includes the surface area of stormwater BMPs that: (1) are wet ponds, OR (2) replace an otherwise impervious surface (e.g., Vegetated Roof, Permeable Pavement).[1]
Managed Turf
Managed turf is grassed soil that no longer functions in its natural hydrological state due to disturbance, compaction, or excessive management. Land disturbed and/or graded for eventual use as managed turf includes: • Portions of residential yards that are graded or disturbed, including yard areas, septic fields, residential utility connections • Roadway rights-of-way that will be mowed and maintained as turf • Turf areas intended to be mowed and maintained as turf within residential, commercial, industrial, and institutional settings

Forest/Preserved Open Space

Land that will remain undisturbed OR that will be restored to a hydrologically functional state:
- Portions of residential yards that will NOT be disturbed during construction
- Portions of roadway rights-of-way that, following construction, will be used as filter strips, grass channels, or stormwater treatment areas; MUST include soil restoration or placement of engineered soil mix as per the design specifications
- Community open space areas that will not be mowed routinely, but left in a natural vegetated state (can include areas that will be bush hogged no more than four times per year)
- Utility rights-of-way that will be left in a natural vegetated state (can include areas that will be bush hogged no more than four times per year)
- Surface area of stormwater BMPs that are NOT wet ponds, have some type of vegetative cover, and that do not replace an otherwise impervious surface. BMPs in this category include bioretention, water quality swale, grass swales, detention pond (used for local flood control requirements) that is not mowed routinely, stormwater wetland, soil amended areas that are vegetated, and infiltration practices that have a vegetated cover.
- Other areas of existing forest and/or open space that will be protected during construction and that will remain undisturbed. These include wetlands.

Operational & Management Conditions for Land Cover in Forest & Open Space Category:
- Undisturbed portions of yards, community open space, and other areas that will be considered as forest/open space must be shown outside the limits of disturbance on approved erosion and sediment control plans AND demarcated in the field (e.g., fencing) prior to commencement of construction.
- Portions of roadway rights-of-way that will count as forest/open space are assumed to be disturbed during construction, and must follow the most recent design specifications for soil restoration and, if applicable, site reforestation, as well as other relevant specifications if the area will be used as a filter strip, grass channel, bioretention, or other BMP
- All areas that will be considered forest/open space for stormwater purposes must have documentation that prescribes that the area will remain in a natural, vegetated state. Appropriate documentation includes: subdivision covenants and restrictions, deeded operation and maintenance agreements and plans, parcel of common ownership with maintenance plan, third-party protective easement, within public right-of-way or easement with maintenance plan, or other documentation approved by the local program authority
- While the goal is to have forest/open space areas remain undisturbed, some activities may be prescribed in the appropriate documentation, as approved by the local program authority: forest management, control of invasive species, replanting and re-vegetation, passive recreation (e.g., trails), limited bush hogging to maintain desired vegetative community, etc.

[1] *Certain stormwater BMPs are considered impervious with regard to the land cover computations. These BMPs are still assigned Runoff Reduction rates within the spreadsheet, so their "values" for stormwater management are still accounted for. The reason they are considered impervious is that they either do not reduce runoff volumes (e.g., wet ponds) or their Runoff Reduction rates are based on comparison to a more conventional land cover type (e.g., vegetated roofs, permeable pavement). In other words, the spreadsheet considers them to be impervious, and then the assigned Runoff Reduction rate reduces the resulting Treatment Volume.*

3.4.2. BMP Design Volume and Credit

Once the Target Tv has been calculated, the designer must select the best BMP or combination of BMPs for the particular development site. As noted previously, the BMP design elements of volume and surface area are determined as a function of the CDA Tv. **Table 3.10** provides a quick reference to those practices that reflect a sizing and design standard for volume (cubic feet) and surface area (square feet). Only two practices, Sheet Flow to Vegetated Filter Strips and Conservation Areas (**Design Specification 4.2.1**), and Impervious Surface Disconnection (**Design Specification 4.2.2**) stand out as the only practices that are sized solely based on surface area and do not have a combined volume and surface area design standard. As expected, these practices are also credited solely based on the surface area provided. It is important to recognize that most BMPs incorporate a surface area design feature that, while not the primary sizing factor, is a critical design feature for ensuring BMP performance and longevity. This combined design element is identified in column 3 of **Table 3.10**.

An example of combined design elements is that of Bioretention (**Design Specification 4.2.3**, includes Residential Rain Gardens, Urban Bioretention and Water Quality Swales) where the design is focused on providing an adequate total storage volume and surface area within the practice. This includes the storage volume elements of surface ponding volume within the soil media and gravel layers, and the additional requirement of establishing a minimum surface area in order to effectively manage the incoming volume and peak rate of runoff.

The Design Compliance Spreadsheet computes the compliance of the BMP implementation strategy by tabulating volume. Even Impervious Surface Disconnection and Sheet Flow practices that are designed to provide a minimum surface area are tabulated in the spreadsheet with a corresponding treatment volume. (A credit of cubic feet is awarded for every square foot of surface area.)

Storage Volume is Just One Critical Design Element

It is important to recognize that most practices will include critical design features in addition to the required storage volume, such as surface area requirements, vegetation, geometry, and other features that are essential for effective management of the Tv.

Table 3.10. Primary BMP Design and Compliance Feature

BMP		Volume Based Load Reduction Credit[1]	Surface Area Based Load Reduction Credit[2]	Combined Volume & Surface Area Design Criteria[3]
Sheet Flow to Conservation Areas			✓	
Sheet Flow to Vegetated Filter Strips			✓	
Simple Disconnection			✓	
Simple Disconnection with Compensatory Practices	Micro-Infiltration	✓		✓
	Residential Rain Garden	✓		✓
	Rainwater Harvesting	✓		
	Urban Planter	✓		✓
Bioretention		✓		✓
Permeable Pavement		✓		✓
Grass Swale		✓		✓
Infiltration		✓		✓
Regenerative Stormwater Conveyance System		✓		✓
Rainwater Harvesting		✓		
Vegetative Roof		✓		✓
Filtration		✓		✓
Stormwater Wetlands			✓	✓

[1]Compliance with permit criteria measured in terms of storage volume provided.
[2] Compliance with permit measured in terms of surface area of the practice.
[3] Minimum design criteria that includes volume and surface area design features.

It is important to note that where Runoff Reduction is credited as a percentage of the incoming runoff volume, it is numerically impossible to achieve compliance with the goal of 100% reduction unless the practice is credited with 100% reduction. For example, a Level 1 Bioretention is credited with removing 60% of the incoming runoff volume when sized for a one-inch rainfall event. Continuing to apply a 60% reduction to the incoming runoff volume will continue to reduce volume and approach the 100% goal, but not reach it. The primary solution for achieving compliance in these cases is to oversize the volume component of the Level 1 BMP to achieve the required volume credit. Using Bioretention as an example, over sizing the storage volume (or Dv) of a Level 1 Bioretention by 167% will achieve the 100% compliance for the specific drainage area being managed.

There are some important limitations and caveats on how these sizing (or oversizing) and crediting rules can be applied. Some are general rules in the application of the Runoff Reduction Method, and others are specific to particular BMPs. **Table 3.11** provides an overview of these key limitations and caveats.

Table 3.11. Sizing Limitations and Caveats for Selected BMPs

1. Runoff Reduction credits cannot be greater than 100% in order to compensate for another drainage area (e.g., 125% Runoff Reduction credit in sub-area 1 to compensate for only achieving 75% Runoff Reduction credit in sub-area 2).
2. **Bioretention**: Design criteria govern the relative size of the surface and subsurface (media) storage volume is specified for Level 1 and Level 2 designs. These criteria are to prevent the extreme cases of creating large surface ponding areas with minimal filter media. Continuing the Dv over sizing example of the Level 1 Bioretention described above, both the design surface area and storage volume must reflect the increased Dv in order to achieve runoff reduction performance values.
3. **Impervious Surface Disconnection**: The previously noted method of crediting Impervious Surface Disconnection and Sheet Flow to Vegetated Filter Strips and Conservation Areas is limited in that there is a maximum size or surface area as a function of the CDA that will limit the "oversizing" of disconnection areas. (These design sizing rules are detailed in the individual design specifications in **Chapter 4**).
4. **Permeable Pavement**: The minimum Permeable Pavement stone reservoir depth required to manage the Tv or Dv will often be less than the stone bedding typically provided under pavement sections as required by the pavement structural design, or the minimum stone depth provided to allow for construction tolerances (i.e. grading for the installation of pavement gravel bedding is typically a "rough grade" depth that will include tolerances of a few inches, whereas the minimum depth of a stone reservoir to manage a 1" rainfall depth may be as little as 2.5 inches). Therefore, most Permeable Pavement installations may be oversized for reasons other than stormwater treatment. The annual volume reduction performance value for Level 1 Permeable Pavement (RR=45%) will not increase with additional volume in the stone reservoir layer because the water does not have a high residence time in the stone (as compared to, say, bioretention soil mix). The Level 1 performance value is capped at 45% (or 0.45 watershed inches), and the Level 2 value at 100% (or one watershed-inch).
5. **Grass Swale**: Grass Swales are designed based on a peak rate of discharge of the Dv (as computed in accordance with **Appendix F**). When a Grass Swale is the downstream BMP in a treatment train, the design and runoff reduction credit can be:
   i. Based on the Dv peak rate of discharge from the upstream BMP and credited with a 10% or 20% runoff reduction credit (depending on soils) applied to the incoming volume; or
   ii. Based on the entire drainage area Tv peak rate of discharge and credited with a 0.1 or 0.2 watershed-inch runoff reduction credit applied to the incoming volume.

   The site designer has the discretion to investigate which approach best suits the site and stormwater design.

Additional BMP specific design criteria in **Chapter 4** will further refine how the BMP storage volume must be configured: geometry, surface storage, media storage, and other factors. Other BMP criteria are less prescriptive and allow the designer to manipulate the practice as needed to fit the site conditions. The design examples in **Chapter 6** illustrate further the application of design criteria.

3.4.3. Large Storm Conveyance

The BMPs in West Virginia will typically be designed to manage the runoff from the one-inch rainfall event. In some cases, designers may be required to manage or detain a larger storm event for purposes of downstream channel protection or flood control. In all cases, the designer must account for the conveyance of these larger storms *through* the BMP (the BMP is said to be **On-Line**) or *around* the BMP (thus making the BMP **Off-Line**). In either case, a bypass control is necessary to manage the large flow so the runoff in excess of the one-inch rain event will not damage the BMP (excessive velocity or ponding depth) or re-suspend and export previously trapped pollutants.

An ***Off-Line*** BMP includes a low-flow diversion structure that channels the small storm flow volume into the BMP, while allowing the larger flows to bypass the BMP. **Figure 3.1** illustrates a simple offline design that diverts the runoff past the Bioretention basin once it has filled up to the maximum design volume depth. **Figure 3.2** illustrates a similar concept using a bypass structure to divert flows past a level spreader. In both cases, larger flows by-pass around the BMP and therefore do not impact the design of the BMP. Bypass structures can be external – thereby diverting the flow before it gets to the BMP, or it can be part of the BMP inlet structure such as a forebay or level spreader.

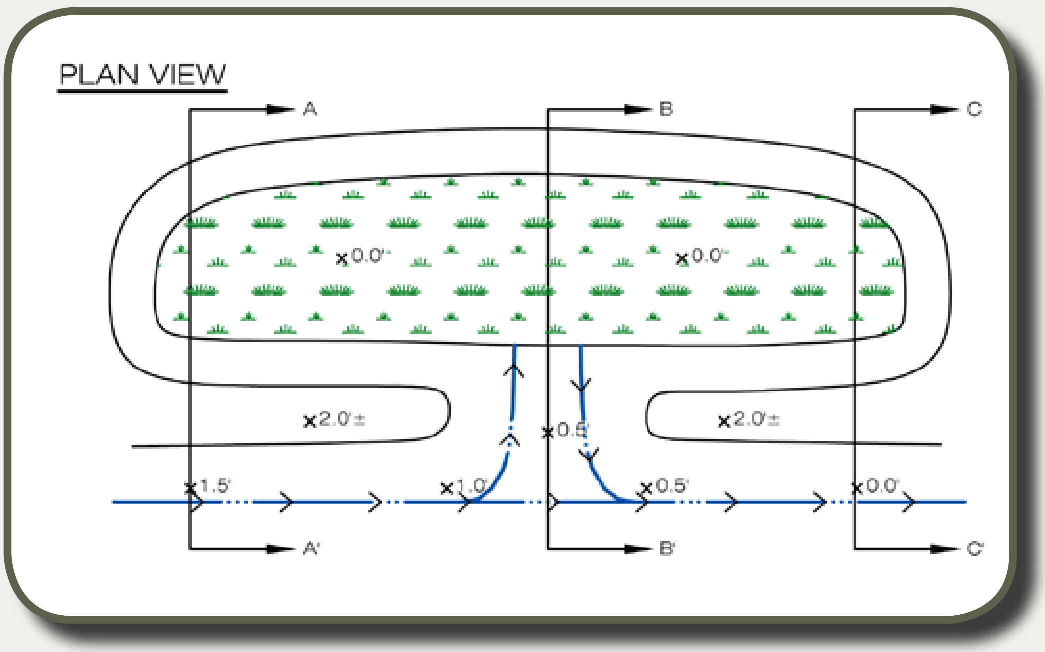

Figure 3.1. Simple Off-Line BMP Design

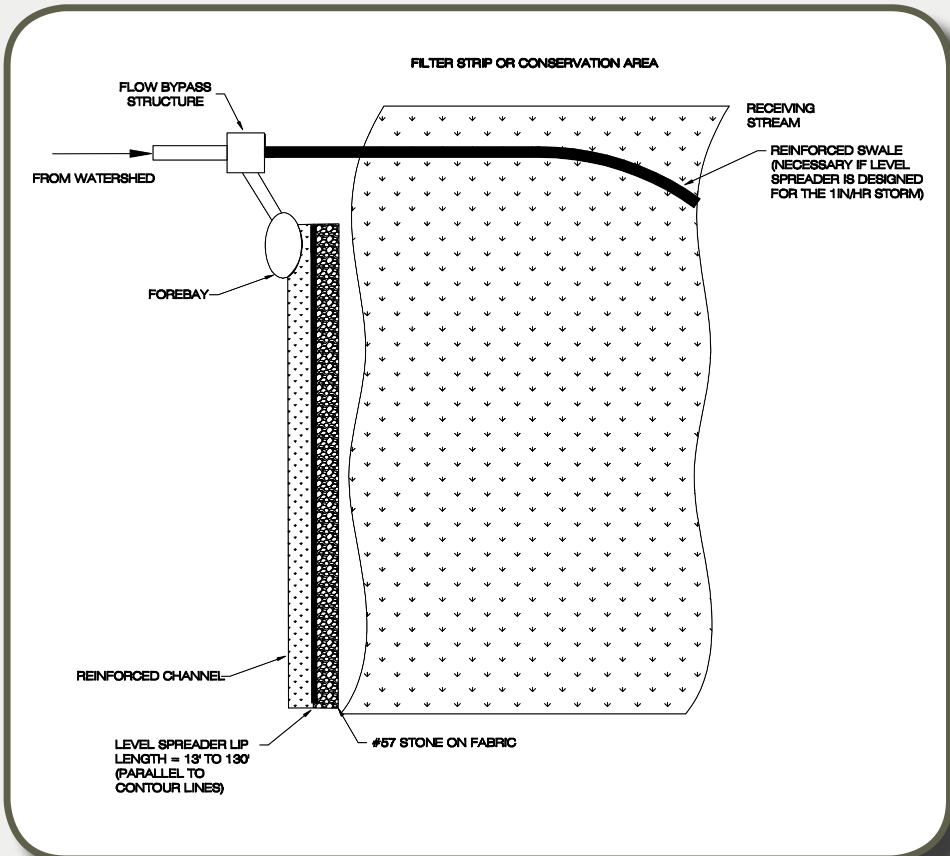

Figure 3.2. External Bypass Structure for Level Spreader

An ***On-Line*** BMP accepts all the runoff from the CDA. Flows that exceed the design capacity exit the practice via an overflow structure or weir within the BMP. On-line BMPs must be carefully designed to accommodate the large storm design peak flow rate in terms of inflow velocity and energy, as well as an adequately sized overflow to allow the runoff to safely exit the BMP.

Off-line designs are usually the preferred option for volume reduction BMPs, especially where larger drainage areas (e.g., greater than 0.5 to 1 acre) are conveyed by a pipe or armored drainage system. On-line systems in these cases will require careful design and construction to ensure adequate conveyance of the large storm inflow.

On-line systems should include the following:

- Inflow points should be protected from erosive velocity;
- An overflow structure must be provided within the practice to pass storms greater than the design storm storage to a stabilized conveyance or storm sewer system;
- Discharge from the overflow structure should be controlled so that velocities are non-erosive at the outlet point;
- The overflow structure type and design should be scaled to the application – this may be a landscape grate or yard inlet for small practices or a commercial-type structure for larger installations.

It should be noted that both types of design approaches require attention to safe conveyance of larger flows in adequate conveyances and with adequate freeboard to a receiving waterbody. Drainage design (pipes, culverts, etc.) should be based on expected peak discharges assuming that upstream volume reduction practices are full.

3.4.4. Large Storm Runoff Reduction Credit

The menu of runoff reduction BMPs available for use includes the Better Site Design strategies described in **Chapter 4, Specification 4.1** (*Watershed Protection Elements*) and the runoff reduction stormwater BMPs outlined in remaining specifications of **Chapter 4** (*Site and Neighborhood Design Elements*). The Watershed Protection Elements include site design strategies that are self crediting; that is, strategies that reduce impervious cover will in turn result in a lower developed condition annual runoff volume as well as the single-event modeled peak rate of runoff by virtue of a lower developed condition runoff Curve Number for all storms. The Runoff Reduction BMPs, as discussed in this chapter, also reduce the annual runoff volume leaving the site. However, additional computations are required in order to incorporate those reductions into single-event hydrologic models.

Peak flow rate reduction for single-event runoff and hydraulic routing models is accomplished by accounting for BMP stage-storage-discharge relationships. Many of the volume based BMPs used in the Runoff Reduction Method provide some amount of storage volume, and designers could apply hydraulic routing relationships. However, the response characteristics of many runoff reduction practices may not follow the traditional detention/retention design parameters. Routing of runoff reduction BMPs can be a difficult and complex task given all the hydrologic and hydraulic variables associated with volume reduction, such as evapotranspiration, storage within the soil media, infiltration, and extended filtration.

The Runoff Reduction Method provides a simpler method for crediting specific runoff reduction values toward peak flow reduction. The method converts the total annual Runoff Reduction credit from all the BMPs in the drainage area from cubic feet (or acre-feet) to watershed-inches of retention storage, and then utilizes the NRCS TR55 runoff e**quations 2-1 through 2-4** to derive a reduced curve number that reflects the reduced runoff volume. This new curve number can then be used for computing the large storm peak discharge from the drainage area for determining the storage volume needed for downstream channel or flood protection requirements.

Adjusted Curve Number and Larger Storm Events

It is unlikely that the reduced curve number will be sufficient to fully comply with any locally-required 2-year or 10-year or larger frequency storm event detention or peak flow standards. However, it may allow for a reduction of the overall size and footprint of structural detention practices, thereby providing an economic incentive to optimize the runoff reduction practices to the maximum extent practicable.

A simplified derivation of the computational procedure starts with the combined NRCS Runoff Equations in order to express the runoff depth in terms of rainfall and potential maximum retention, TR-55 **Equations 2-1 through 2-3.** In addition, the potential maximum retention, S, is related to soil and cover conditions of the watershed through the curve number as described by TR-55 **Equation 2-4**.

(Eq. 2-1, TR-55)
$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

(Eq. 2-2, TR-55)
$$I_a = 0.2S$$

(Eq. 2-3, TR-55)
$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

(Eq. 2-4, TR-55)
$$S = \frac{1000}{CN} - 10$$

(Modified Eq. 2-3)
$$Q - R = \frac{(P - 0.2\,S)^2}{(P + 0.8\,S)}$$

where:

Q = runoff depth (in),
P = rainfall depth (in),
I_a = Initial abstraction (in),
S = potential maximum retention after runoff begins (in),
CN = Runoff Curve Number, and
R = Retention storage provided by Runoff Reduction practices (in).

The retention storage depth equivalent to the Runoff Reduction values assigned by the Runoff Reduction Method, and any additional retention storage provided on the site (expressed in terms of retention storage R) is subtracted from the total runoff depth associated with the developed condition curve number, which then will provide for a new value of S (**Modified Equation 2-3**). A new curve number is then back-calculated from the new value of S using **Equation 2-4** (Koch, 2005).

While it is not easy to predict the absolute runoff hydrograph modification provided by reducing stormwater runoff volumes, it is clear that reducing runoff volumes will have an impact on the runoff hydrograph of a development site. Simple routing exercises have indicated that this curve number adjustment approach represents a conservative estimate of peak reduction.

This procedure is simplified for designers in the Design Compliance Spreadsheet. It is important to note that the curve number reduction associated with the retention of one watershed-inch of runoff volume will decrease as the rainfall depth increases (meaning one-inch of volume reduction has less of an impact on a five-inch rain event than it will on a two-inch rain event). Therefore, the curve number adjustment must be computed for each design storm depth.

3.4.5. Evaluating BMP Compliance – The Design Compliance Spreadsheet

The Design Compliance Spreadsheet is a tool that integrates the runoff volume reduction methods and stormwater BMP performance values discussed in this chapter. The spreadsheet is primarily a tool to be used by site designers and local program plan reviewers to evaluate compliance with the 1-inch capture performance goal in the MS4 General Permit. While its primary function is as a compliance tool, the spreadsheet can also be used by site designers as a stormwater BMP planning tool. The spreadsheet allows the designer to develop and test various BMP scenarios and preliminary sizing guidelines in a relatively quick and efficient manner.

The following is a quick overview of the tabs and capabilities of the Design Compliance Spreadsheet:

- A **Site Data** tab allows the user to input proposed land covers by drainage area. The tab uses the Runoff Reduction Method calculations outlined in this chapter to derive the post-development Treatment Volume for each drainage area. This tab also applies the volume "credits" associated with any Incentive Standards that apply to the site (e.g., redevelopment, brownfields, high density, etc.).
- Individual **Drainage Area** tabs allows the user the run various BMP scenarios, using different combinations of BMPs and BMP storage volume/surface area scenarios to accomplish the Treatment Volume objectives. These tabs include all the BMPs in this manual that are assigned a runoff volume reduction performance value.
- A **Runoff Reduction Summary** tab tracks cumulative volume reductions from the BMPs in the Drainage Area tabs, and compares this value to the required Treatment Volume. This is essentially a quick compliance check.
- A **Channel and Flood Protection** tab utilized the Curve Number adjustment method outlined in **Section 3.4.4**, yielding adjusted Curve Numbers for each drainage area, depending on the cumulative runoff reduction volume achieved. These adjusted Curve Numbers can be used, at the discretion of the local plan approving authority, to model compliance with local stormwater detention and/or channel and flood protection requirements.

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Chapter 4: Stormwater BMP Specifications

Chapter 4 provides detailed design specifications for stormwater best management practices (BMPs) that can be used to meet the runoff reduction performance standard. The practices in Chapter 4 include:

4.1. Better Site Design Practices
4.2. BMPs With Assigned Runoff Reduction and/or Pollutant Removal Performance Values
4.2.1. Sheet Flow to Vegetated Filter Strips and Conservation Areas
4.2.2. Impervious Surface Disconnection
- Simple Disconnection
- Simple Disconnection with Soil Amendments
- Disconnection with Compensatory Practices

4.2.3. Bioretention
- Traditional (main chapter)
- Water Quality Swale (Supplement 4.2.3.A)
- Urban Bioretention (Supplement 4.2.3.B)
- Residential Rain Garden (Supplement 4.2.3.C)

4.2.4. Permeable Pavements (permeable interlocking concrete pavers, pervious concrete, porous asphalt, concrete grid pavers)
4.2.5. Grass Swales
4.2.6. Infiltration (dry wells, infiltration trenches, infiltration basins)
4.2.7. Regenerative Stormwater Conveyance System
4.2.8. Rainwater Harvesting (cisterns and rain tanks)
4.2.9. Vegetated Roofs (intensive and extensive)
4.2.10. Filtration (surface sand filters, underground sand filters, perimeter sand filters) – **water quality credit only**
4.2.11. Stormwater Wetlands (subsurface gravel wetlands, wetland basins, multi-cell wetland or pond/wetland combination) – **water quality credit only**

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BSD-1. Introduction

Part II, Section C.b.5.a.i of the MS4 General Permit outlines the Watershed Protection elements of Minimum Measure #5. This section requires the MS4 or permittee to incorporate six Watershed Protection Elements into local development codes, policies, and ordinances, as well as comprehensive and master plans for land use, transportation, and neighborhoods. The six elements include:

1. Minimize impervious surfaces
2. Preserve, protect, create and restore ecologically sensitive areas
3. Prevent or reduce thermal impacts to streams
4. Avoid or prevent hydromodification of streams and other waterbodies
5. Protect trees and other vegetation
6. Protect native soils

Collectively, these techniques can be referred to as "better site design" (BSD) practices.

Better Site Design Practices Reduce the Design Treatment Volume

It is important to note that BSD practices create a link between the Watershed Protection and Site and Neighborhood Design Elements of the MS4 General Permit. Specifically, the use of these practices – by reducing impervious cover, managed turf, and site disturbance – will reduce the Target Treatment Volume associated with the one-inch rainfall event that must otherwise be managed by structural stormwater BMPs. In essence, BSD techniques provide cost-effective ways to reduce the Target Treatment Volume while providing multiple environmental benefits on a development or redevelopment site. Another benefit is that these practices can reduce permitting time and costs associated with stream corridor, wetland, and floodplain impacts.

Because of this relationship, BSD practices are referred to as "self-crediting." In other words, they do not have an assigned runoff reduction and/or pollutant removal rate as do the other BMPs in **Chapter 4**. However, they do help manage the one-inch Target Treatment Volume and should be considered early in the site planning process as "the first BMP."

See **Chapter 2** for a description of each Watershed Protection Element, and the MS4 General Permit and associated fact sheet for more detailed information on these elements and their benefits. The chief function of this section of the Manual is to more specifically identify the practices and conditions under which each can be considered a "self-crediting" BSD technique.

The specific BSD practices addressed in this section include:

- Preserve Undisturbed Natural Areas; Preserve and Protect Ecologically Sensitive Areas; Protect Trees and Other Vegetation
  - o Preserve Riparian Corridor; Reduce Thermal Impacts to Streams
  - o Preserve Natural Drainage Features/Incorporate Designs that Reduce Stream Impacts & Hydromodification
  - o Preserve Valuable Habitat Areas
- Preserve Porous and Erodible Soils; Protect Native Soils
- Preserve Steep Slopes
- Reduce Clearing and Grading Limits
- Reduce Setbacks and Frontages; Minimize Impervious Surfaces
- Reduce Roadway Lengths and Widths
- Reduce Sidewalk and Driveway Lengths and Widths
- Use Fewer or Alternative Culs-de-Sac
- Reduce Parking Lot Footprints
- Create Landscaping Areas in Parking Lots
- Reduce Building Footprints

The following sections outline the process of conducting a natural resources inventory so that these practices can successfully be incorporated into development designs, and also provide a brief overview of each BSD practice. Each practice description includes a "checklist" of standards that characterize successful implementation of the practice. It should be noted that any individual development design may not be able to incorporate all of the standards. Local program staff should work with developers and designers to incorporate the most appropriate elements on a given site.

BSD-2. Natural Resources Inventory

Conduct a Natural Resources Inventory at an Early Stage of Site Planning

In order to effectively incorporate some or all of the BSD practices into a development or redevelopment site, it is important as an early step in site planning to conduct a natural resources inventory to identify existing site conditions. This inventory can then serve as a basemap to explore different development designs and layouts that help accomplish various BSD objectives. A template for a natural resource inventory checklist is provided below.

Checklist for Natural Resources Inventory

Conduct the inventory at an early stage of site planning well before infrastructure and site layouts are locked down. The inventory should include the following (among other site-specific features):

- ❑ Soils: conducive to infiltration and/or most susceptible to erosion or instability
- ❑ Slopes: greater than 15% and greater than 25%
- ❑ Streams and drainage patterns
- ❑ Floodplains
- ❑ Probable wetlands
- ❑ Vegetation: forests, sensitive habitat areas
- ❑ Special natural resource areas, such as cold-water stream habitats, viewsheds, groundwater recharge or drinking water source protection areas
- ❑ Degraded areas that could be restored as part of an overall stormwater/site plan strategy
- ❑ Evidence of past mining activities that may affect surface water and groundwater interactions

4.1 "Self-Crediting" Better Site Design (BSD) Practices

BSD-3. Preserve Undisturbed Natural Areas; Preserve and Protect Ecologically Sensitive Areas; Protect Trees and Other Vegetation

Important terrestrial and aquatic resources, such as stands of trees and/or other vegetation, perennial and intermittent streams, wetlands, groundwater recharge areas and other important natural resources (e.g., wellhead protection areas) should be delineated and protected on development and redevelopment sites as natural resource conservation areas. Protecting natural resources on a development site helps preserve existing site hydrology, aids in reducing post-development stormwater runoff rates, volumes and pollutant loads and helps prevent soil erosion and provides areas that can be used to treat post-construction stormwater runoff generated elsewhere on the site (see **Specification 4.2.1: Sheet Flow to Vegetated Filter Strips and Conservation Areas**).

Standards that characterize this practice include:

- ❑ Identify natural areas as part of natural resources inventory.
- ❑ Identify one or several contiguous and/or interconnected areas for conservation; avoid too much fragmentation of areas across the site.
- ❑ Clearly show areas on all site plans and clearing and grading plans; note on these plans that area is to remain undisturbed and construction equipment should be kept out of these areas.
- ❑ Show some type of barrier or fencing (e.g., orange fencing) along the boundaries of natural areas on the erosion and sediment control plan (**Figure BSD-1**).
- ❑ Provide a mechanism for the long-term protection of natural areas, such as legally-enforceable deed restrictions, homeowner covenants and maintenance agreements, and/or conservation easements.
- ❑ Provide a maintenance agreement that clearly assigns long-term maintenance responsibility with specific management standards, practices, and objectives.
- ❑ Ensure that the areas are protected during construction.
- ❑ Provide signage and other landowner educational material to help inform residents about the function and management of the natural areas.

Figure BSD-1. Fencing to delineate limits of clearing and protect trees

Several specific BSD approaches can be considered subsets of the overarching practice of preserving natural areas:

- Preserve riparian corridors; reduce thermal impacts to streams
- Preserve natural drainage features
- Preserve porous soils
- Preserve steep slopes
- Preserve valuable habitat areas

Each is dealt with in turn below.

A. Preserve Riparian Corridor; Reduce Thermal Impacts to Streams

This is perhaps the most important subset of the practice outlined in **BSD-3**. Existing riparian corridors should be delineated and preserved as natural resource conservation areas on development and redevelopment sites. Intact riparian corridors provide the shading necessary to minimize thermal impacts while providing organic matter for aquatic organisms, slowing the velocity of flood waters, and allowing the flood waters to be absorbed into the ground or the floodplain instead of causing damage downstream. Riparian buffers provide a filter to remove sediment and other particles in stormwater as well as the pollutants which adhere to the particulates. In addition to being critical for stormwater management functions, headwaters, floodplains, and wetlands all serve a wide variety of ecological functions such as flood control, nursery habitat, and production of food to maintain fisheries.

- ❑ Clearly identify the riparian corridor on clearing and grading plans as natural resource conservation areas; note on these plans that the area is to remain undisturbed and construction equipment should be kept out of these areas. If development does occur in these areas, outline mitigation measures.
- ❑ Clearly mark the boundaries of the riparian corridor with temporary construction fencing prior to the start of land development activity.
- ❑ Provide a fixed or variable width riparian buffer; avoid too much fragmentation of the area. Provide a minimum 25-foot vegetated riparian buffer and an additional 75-foot development setback, which can managed as meadow transitioning to turf. A 100 foot natural vegetated buffer is strongly encouraged to achieve greater stormwater management and wildlife habitat value.
- ❑ As an alternative, a site design can use "buffer averaging." The average width of the riparian buffer across the site should be at least 50 feet, while no section of buffer should be less than 25 feet.
- ❑ Limit future development in the riparian corridor to structures necessary to protect human health and safety; include restrictions in final plat and deed.

B. Preserve Natural Drainage Features/Incorporate Designs that Reduce Stream Impacts & Hydromodification

Natural drainage features and patterns should be preserved by "designing with the landform" on development and redevelopment sites. Preserving these natural drainage features helps preserve existing site hydrology and reduces post-development stormwater runoff rates, volumes and pollutant loads. As appropriate, natural drainage features can be protected as natural resource conservation areas (see **BSD-3**).

- ❑ Locate buildings and impervious surfaces a minimum of 25 feet from natural drainage features (e.g. intermittent streams, wetlands) and out of the riparian corridor.
- ❑ Orient the major axis of buildings and other structures parallel to existing contours.

C. Preserve Porous Soils; Protect Native Soils

Pockets of porous soils, such as sands, sandy loams, and loamy sands, should be delineated and preserved on development and redevelopment sites. Sites that use mass grading will find this practice difficult and should consider the use of phased clearing. Native soils, especially topsoil, contain important organic materials generally not present in underlying soil layers.

In areas with thin soil layers (in many parts of West Virginia), pockets of porous soils are especially critical. Topsoil layers are often stripped off prior to or during construction operations. Also, construction and equipment access can compact soils so that they lose most of their ability to infiltrate stormwater and become effectively impervious. Native porous soils provide opportunities for the passive and active (engineered) infiltration of stormwater runoff and can be used to manage stormwater runoff generated elsewhere on the development site.

On sites with past mining activity, it is important to examine soils and groundwater to identify disturbed soils and how surface water/groundwater interactions may have been disrupted.

- ❑ Clearly identify porous soils and unstable and erodible soils on clearing and grading plans and the site layout or design as natural resource conservation areas to protect.
- ❑ Locate buildings and other impervious surfaces in areas with tight soils with the lowest infiltration rates (e.g. hydrologic soil group C and D soils).
- ❑ As appropriate, use areas of porous soils for Sheet Flow to Conservation Areas (**Specification 4.2.1**) and engineered Infiltration practices (**Specification 4.2.6**). For the latter, it is important to provide field verification of soil types and profiles compared to information in the soil survey.

D. Preserve Steep Slopes

During site layout and design, steep slopes should be avoided due to the potential for soil erosion and increased sediment loading. Sites that use mass grading will find this practice difficult and should consider the use of phased clearing. In West Virginia, many larger development sites are characterized by large cuts and fills, valley fills, and the creation of engineered steep slopes. In these cases, the pre-development slopes are less of an issue. However, many smaller or less intensive sites can do a better job of working with the pre-development topography and reducing the extent of site grading.

- ❑ Minimize excessive grading and flattening of slopes.
- ❑ Clearly identify slopes of 15% or greater on development plans; avoid excess clearing and grading; leave rolling terrain undisturbed where possible.
- ❑ Avoid land development activities in areas that have slopes greater than 25% unless necessary for roadway or utility construction.

E. Preserve Valuable Habitat Areas

Undisturbed natural areas that provide habitat for special ecological communities and rare plants and wildlife should be delineated and protected as natural resource conservation areas on development and redevelopment sites. A valuable habitat area is a special type of natural resource conservation area that provides a critical, protective environment for special ecological communities and rare plants and wildlife where development and disturbance is significantly restricted or prohibited.

- ❑ Identify valuable habitat areas as part of natural resources inventory.
- ❑ Clearly show areas on all site plans and clearing and grading plans; note on these plans that area is to remain undisturbed during construction and occupancy and construction equipment should be kept out of these areas.
- ❑ Clearly mark the boundaries of the valuable habitat areas with temporary construction fencing prior to the start of land development activity.

4.1 "Self-Crediting" Better Site Design (BSD) Practices

BSD-4. Reduce Clearing and Grading Limits

This practice is clearly interrelated with all of the practices discussed in **4.1.3**. Clearing and grading on development and redevelopment sites should be limited to the minimum amount needed for building footprints, infrastructure, and construction access. The land development process of clearing, grading and compaction can significantly reduce the ability of disturbed pervious areas to reduce post-development stormwater runoff volumes (Law et al., 2008; Schueler, 2000).

- ❑ Use "site fingerprinting," which is the process of mapping all of the limits of disturbance on a development or redevelopment site to identify the smallest possible land area that requires clearing and grading.
- ❑ Establish limits of disturbance that are based on maximum disturbance zone radii/lengths. These maximum disturbance zones should reflect the needs of the construction equipment and techniques that will be used as well as the physical characteristics of the development or redevelopment site.
- ❑ Where possible, use phased construction on larger sites. Each 20 acres of disturbance (or a locally appropriate threshold) should be stabilized before moving on to the next 20 acres. This will require balancing of cuts and fills within each phase.

4.1 "Self-Crediting" Better Site Design (BSD) Practices

BSD-5. Reduce Setbacks and Frontages

The intent of this BSD practice is to create more compact development footprints so that other areas of the site can be preserved. Using smaller setbacks and narrower frontages to reduce roadway, driveway and sidewalk lengths helps to minimize the creation of new impervious cover. Reducing front yard and side yard setbacks and using narrower frontages helps create compact site designs with reduced total street lengths. Reduced setback and frontage distances also allow site planning and design teams to use flexible lot shapes and "design with the landform," which helps minimize land disturbance. This practice is obviously related to local zoning, subdivision, and other development codes, and may be used most appropriately in certain zoning districts where conservation or open space design is authorized.

- ❑ Allow for front yard setbacks to 20 feet.
- ❑ Allow for side yard setbacks to 25 feet or less.
- ❑ Allow for narrower frontages of 80 feet or less.

4.1 "Self-Crediting" Better Site Design (BSD) Practices

BSD-6. Reduce Roadway Lengths and Widths

Roadway lengths and widths can be minimized to help reduce the creation of new impervious cover. Generally, compact site designs that make use of smaller lot sizes and reduced setbacks and frontages help reduce total street length. Site planning and design teams should strive to create site layouts that include smaller lots located off a few main roadways instead of site layouts that include long streets serving a relatively small number of large lots. In addition to minimizing street length, site planning and design teams should seek to reduce residential street width, as well as commercial, institutional and industrial street width, to the minimum needed to support travel, on-street parking and emergency, maintenance and service vehicle access. As with BSD-5, this is strongly linked with local development codes.

- ❑ Design development sites to include smaller lots located off a few main roadways instead of site layouts that include long streets serving a relatively small number of large lots.
- ❑ Reduce on-street parking to one lane or eliminate on local cul-de-sac and two-way loop roads.
- ❑ Use one-way single-lane loop roads.
- ❑ Reduce road width requirements for the minimum required pavement width needed to support travel lanes; on-street parking; and emergency, maintenance, and service vehicle access (**Figure BSD-2**). For local streets with less than 500 average daily trips, reduce road width to:
- ❑ 18 feet where parking is not expected or is restricted to one side
- ❑ 20-22 feet where parking is permitted on either side of the street.
- ❑ 22-24 feet for streets that provides a combination of on-street parking and moving lanes.
- ❑ Use Grass Swales (**Specification 4.2.5**) or Water Quality Swales (**Specification 4.2.3.A**) to treat roadway runoff .
- ❑ Consider Permeable Pavement (**Specification 4.2.4**) for parking and/or travel lanes in appropriate settings.

Figure BSD-2. Reduced Street Width

4.1 "Self-Crediting" Better Site Design (BSD) Practices

BSD-7. Reduce Sidewalk and Driveway Lengths and Widths

Sidewalk and driveway lengths and widths can be minimized to help reduce the creation of new impervious cover. Excessive sidewalk and driveway lengths and widths can significantly increase the amount of new impervious cover created on development sites, resulting in an increase in post-development stormwater runoff rates, volumes and pollutant loads. In fact, as much as 20% of the impervious cover in a typical residential subdivision may consist of sidewalks and driveways (CWP, 1998).

- ❑ Develop site layouts that minimize the overall sidewalk and driveway length in cases where additional sidewalk length is not needed for public safety or urban redevelopment.
- ❑ Locate sidewalks on only one side of the street.
- ❑ Use sidewalk widths of six feet in areas with higher foot traffic and four feet in areas with lower use.
- ❑ Use shared driveways where applicable to the design.
- ❑ Use alternative driveway designs, such as runner strips (**Figure BSD-3**).
- ❑ Use alternative or permeable surfaces, such as crushed rock or permeable pavement for sidewalk and driveway construction.

Figure BSD-3. Alternative driveway design with runner strips

4.1 "Self-Crediting" Better Site Design (BSD) Practices
BSD-8. Use Fewer or Alternative Culs-de-sac

The use of fewer or alternative culs-de-sac should be used to help minimize the amount of new impervious cover created on development and redevelopment sites. The dimensions of culs-de-sac should be reduced to the minimum area needed to accommodate emergency, maintenance and service vehicles and alternative cul-de-sac designs should be considered.

- ❑ Use alternative cul-de-sac designs that include landscaping islands, 30-foot radii, hammerheads and loop roads.
- ❑ Create landscaping islands located within culs-de-sac (**Figure BSD-4**). In cases where site grades allow, these islands can be used to manage stormwater runoff generated elsewhere on the development site (see **Specification 4.2.3, Bioretention**).

Figure BSD-4. Cul-de-sac with bioretention island

4.1 "Self-Crediting" Better Site Design (BSD) Practices
BSD-9. Reduce Parking Lot Footprints

Reduce the amount of new impervious cover created on development and redevelopment sites by revising parking lot design. Parking lots are the largest component of impervious cover in most commercial and industrial zones.

- ❑ Use the average parking demand for parking lot design instead of the highest hourly parking demand during the peak shopping season. This will still accommodate the parking demand for most of the year and create less impervious cover.
- ❑ Minimize the dimensions of parking spaces by reducing the length and width of parking stalls to 9 ft by 18 ft.
- ❑ Provide compact car spaces.
- ❑ Use alternative paving surfaces (Permeable Pavement **Specification 4.2.4**) for parking lot construction.
- ❑ Where applicable, provide structural parking facilities.
- ❑ Use shared parking where two adjacent land uses have peak demand parking at different times of the day or week (e.g. church and office building).

4.1 "Self-Crediting" Better Site Design (BSD) Practices

BSD-10. Create Landscaping Areas in Parking Lots

Reduce the amount of new impervious cover created on development and redevelopment sites by distributing landscaping areas, such as landscaping islands and buffer strips, throughout parking lots (**Figure BSD-5**).

- ❑ Design landscaping areas in parking lots as stormwater management practices that can treat stormwater runoff (**Specifications 4.2.1, Sheetfow to Vegetated Filter Strips, and 4.2.3, Bioretention**).
- ❑ Use long landscaping areas that are at least six feet wide and contain porous soils with enough organic matter and nutrients to support plant growth, especially trees (Cappiella et al., 2006).
- ❑ Use curb cuts to convey post-construction stormwater runoff from parking lots into these landscaping areas.

Figure BSD-5. Parking lot landscaping area that provides stormwater management

4.1 "Self-Crediting" Better Site Design (BSD) Practices

BSD-11. Reduce Building Footprints

Site planning and design teams can consolidate functions and buildings to create taller building designs that have smaller impervious footprints.

- ❑ Consider designing buildings with smaller footprints instead of large single story structures.

REFERENCES

Cappiella, K., Schueler, T., and T. Wright. 2006. Urban Watershed Forestry Manual. Part 2: Conserving and Planting Trees at Development Sites. NA-TP-01-06. USDA Forest Service, Northeastern Area State and Private Forestry. Newtown Square, PA.

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Law, N.L., K. Cappiella and M.E. Novotney. 2008. "The Need to Address Both Impervious and Pervious Surfaces in Urban Watershed and Stormwater Management." Journal of Hydrologic Engineering. 14(4): 305-308.

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4.2.1. Sheet Flow to Vegetated Filter Strips and Conservation Areas (SF)

SF-1. Introduction

Sheet Flow to Vegetated Filter Strips and **Sheet Flow to Conservation Areas** represent the practice of using adjacent vegetated areas to manage stormwater runoff by slowing runoff velocities and allowing sediment and attached pollutants to settle and be filtered by the vegetation.

Vegetated Filter Strips can be within the limits of disturbance on a development site and are engineered to minimum specifications, constructed, and stabilized with vegetation. However, effort should be made to preserve native vegetation if at all possible for a Vegetated Filter Strip

Conservation Areas are areas that meet minimum criteria in their natural condition, are protected from impacts during construction, and are protected from impacts after construction with an easement or other protective covenant. Conservation Areas can include stream buffers and can be reforested or enhanced with a vegetation management plan designed to support preferred vegetation, but are otherwise left undisturbed.

In both cases, stormwater runoff must enter the Filter Strip or Conservation Areas as sheet flow. Inflow from a pipe or channel can be converted to sheet flow with an engineered level spreader.

Sheet Flow to Vegetated Filter Strips and Conservation Areas can be used to:

- Partially manage the first one-inch of rainfall on-site (in conjunction with upgradient practices) when applying Sheet Flow to Vegetated Filter Strips or Conservation Areas with various Hydrologic Soil Groups (HSGs) (see **Table SF-1** and **Table SF-2**). Runoff reduction for Vegetated Filter Strips in C/D soils can be enhanced by using Soil Amendments (see **Appendix D**)

<u>Note: Soil Amendments do not generally apply to Sheet Flow to Conservation Areas since these areas are typically left undisturbed. The exception would be areas that are restored and reforested to act as conservation areas. (see **Section SF- 4.4**).</u>

- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs) (See **Tables SF-3 and SF-4**)
- Retrofit existing developed areas

Vegetated Filter Strips and Conservation Areas can be incorporated into any green space and/or buffer (stream, screening, or other) requirements on site. **Figure SF-1** illustrates some typical applications for these practices, and **Figures SF-2 and SF-3** are schematics showing design characteristics outlined in this specification. **Table SF-5** is a design checklist to help guide the design process for the practices.

SF-1.1. Planning This Practice

Figure SF-1. Typical applications for Sheet Flow to Vegetated Filter Strip and Conservation Area

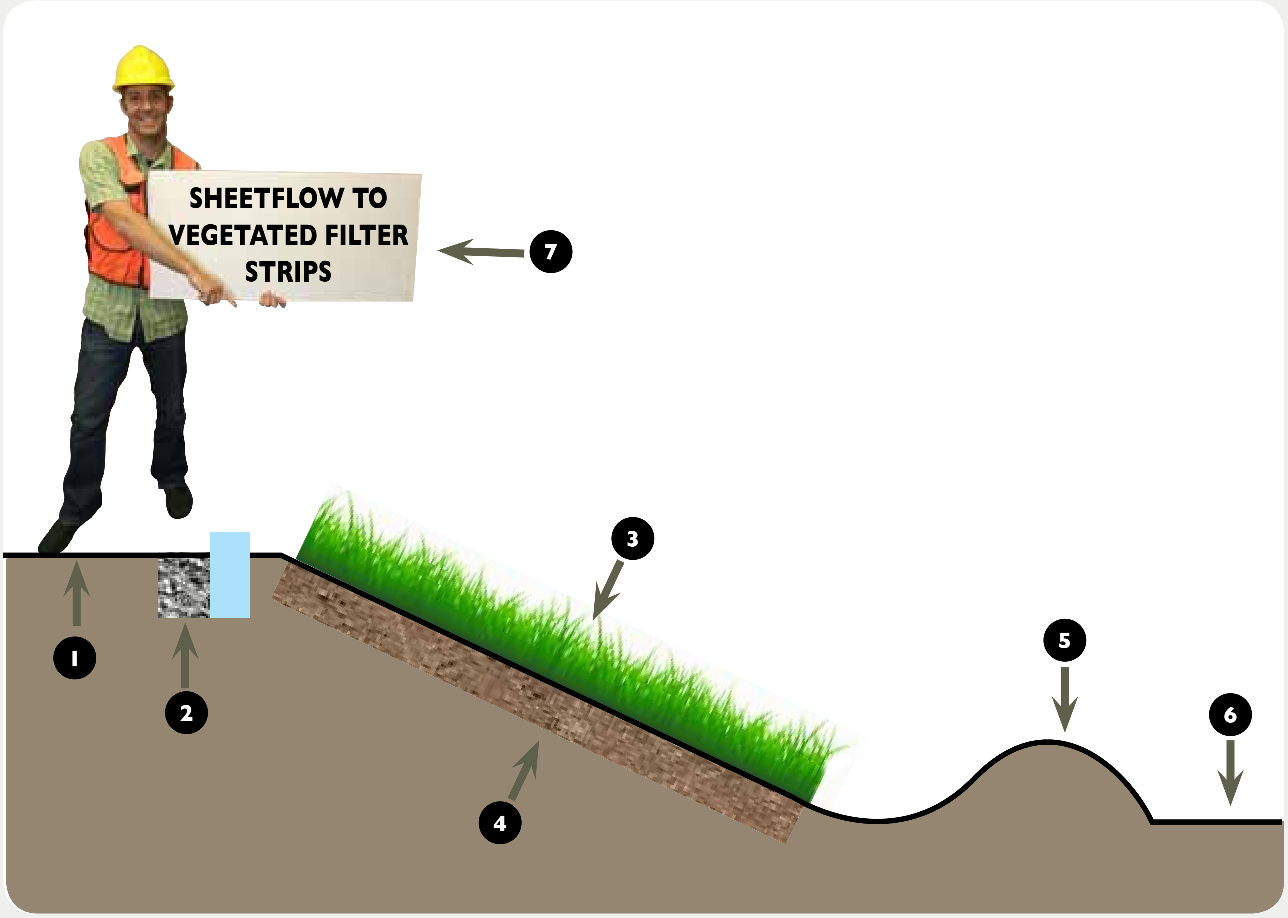
Sheet Flow from small impervious area to Vegetated Filter Strip

Enhancing runoff reduction with Soil Amendments

Sheet Flow to Conservation Area (stream buffer) along with Reforestation

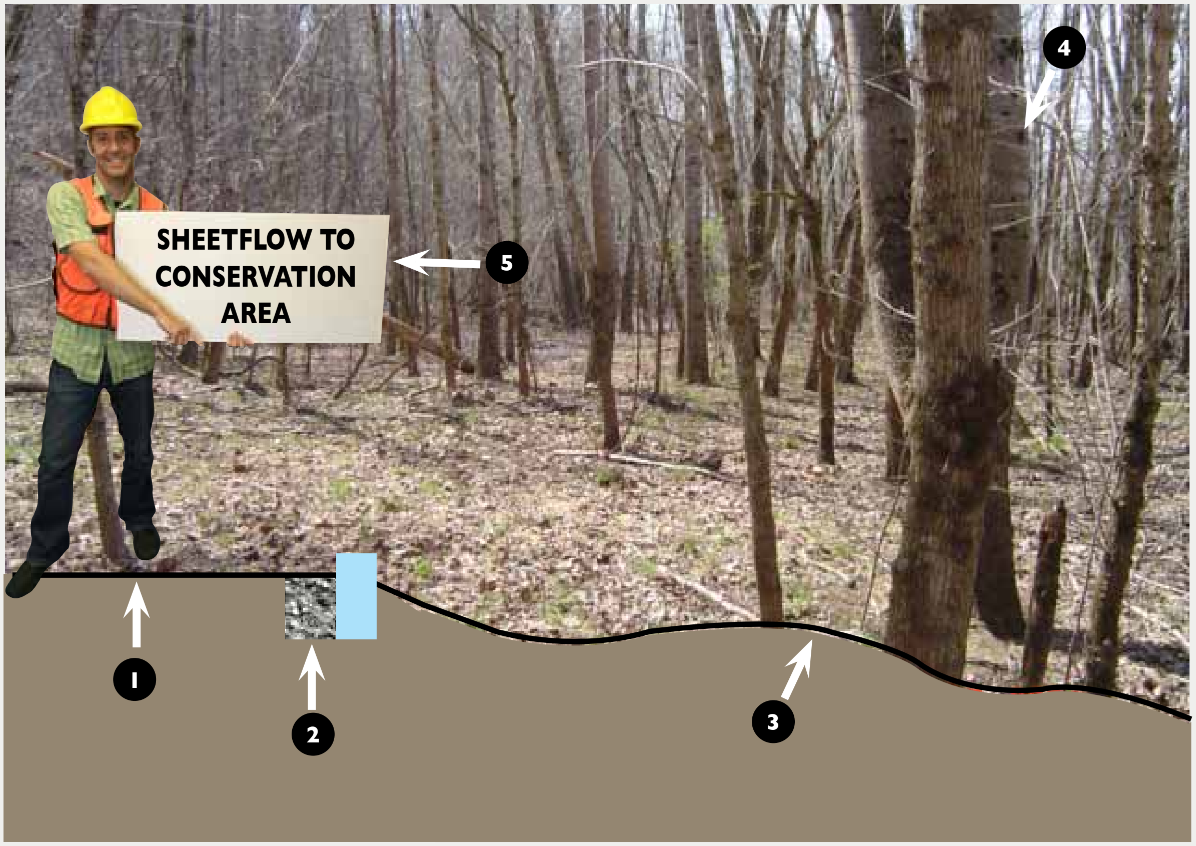
Waterway buffer sign used to mark boundary of Conservation Area

Figure SF-2. Schematic for Sheetflow to Vegetated Filter Strip



1. **Contributing impervious or pervious flow path** – Table SF-1 & Section SF-3.2
2. **Pretreatment gravel diaphragm/level spreader** – Section SF-4.2
3. **Vegetated filter strip (slope, width, vegetation)** – Table SF-1, Sections SF-3.2 & SF-4.4
4. **Soil amendments** – Section SF-4.1 & Appendix D of Manual
5. **Permeable berm** – Section SF-4.2
6. **Transition to natural vegetation or downstream BMP**
7. **Signage** – Section SF-4.5

Figure SF-3. Schematic for Sheetflow to Conservation Area



1. **Contributing impervious or pervious flow path** – Table SF-1 & Section SF-3.2
2. **Pretreatment gravel diaphragm/level spreader** – Section SF-4.2
3. **Conservation area (slope, geometry)** – Table SF-2 & Section SF-3.1
4. **Conservation area (vegetation)** – Section SF-4.4 & Appendix F of Manual
5. **Signage** – Section SF-4.5

SF-1.2. Sheet Flow to Filter Strips and Conservation Areas Design Options & Performance

Table SF-1 describes the basic design options for Sheet Flow to Vegetated Filter Strips and **Table SF-2** provides the same for Sheet Flow to Conservation Areas and the corresponding performance in terms of reducing the volume associated with one-inch of rainfall on the site. **Tables SF-3** and **SF-4** summarize the corresponding pollutant removal performance values for the two practices. Pollutant removal is provided for the purpose of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans.

Table SF-1. Sheet Flow to Vegetated Filter Strips Description & Performance

Hydrologic Soil Group	Description	Applications	Performance[1]
A / B[2]	Standard Design – Geometry Slope and width[3]: 1% to 4% - min 35 ft. width; 4% to 6% - min 50 ft. width; 6% to 8% - min 65 ft. width; First 10 ft. must be ≤ 2% in all cases Inflow Sheet Flow: Pervious areas: max flow length ≤ 150 ft.; Impervious areas: max flow length ≤75 ft.; Concentrated Flow: ELS[4] lip = 13 lin. ft. per 1 cubic foot per second (cfs) Pre-Treatment: GD[4] at top of filter PB[4] at bottom of filter	Treat small areas of impervious cover (e.g., 5,000 sq. ft.); and/or Moderate areas (10,000 sq. ft.) turf-intensive land uses (sports fields, golf courses) close to source	6 $ft.^3$ of volume reduction for every 100 $ft.^2$ of Filter Strip
C / D	Standard Design – Same as A/B soils	Same as A/B Soils	3 ft^3 of volume reduction for every 100 ft^2 of Filter Strip
C / D	Soil Amendments Same as A/B soils Filter Strip soil amendments[5]	Same as A/B Soils	6 $ft.^3$ of volume reduction for every 100 $ft.^2$ of Filter Strip

[1] Performance achieved toward reducing runoff from a one-inch rainfall.
[2] The plan approving authority may require verification of soil types, especially if the soils are disturbed during construction. Restoration of disturbed A/B soils should be verified in order to achieve the A/B HSG performance credit.
[3] Vegetated Filter Strips used during construction (Specification 3.25 in WVDEP, 2006) are required to be a minimum of 100 ft. in width to manage sediment loads typical of active construction sites.
[4] ELS = Engineered Level Spreader; GD = Gravel Diaphragm; PB = Permeable Berm
[5] Refer to Appendix D for Soil Amendment specifications

Table SF-2. Sheet Flow to Conservation Areas Description & Performance

Hydrologic Soil Group	Description	Applications	Performance[1]
A / B	Standard Design – Geometry • Slope: - 0.5% to 3% - min 35 ft. width; - 3% to 6% - min 50 ft. width; - First 10 ft. must be ≤ 2% in all cases[2] Inflow • Sheet Flow: - Pervious areas: max flow length ≤ 150 ft.; - Impervious areas: max flow length ≤75 ft.; • Concentrated Flow: - ELS[3] lip = 13 lin. ft. per 1 cfs for areas with 90% vegetative cover[4]; - ELS lip = 40 lin. ft. per 1 cfs for forested or re-forested areas length Pre-Treatment: • GD[3] at top of Conservation Area	Adjacent to stream or wetland buffer or forest Conservation Area	9 $ft.^3$ of volume reduction for every 100 $ft.^2$ of Conservation Area
C / D	Standard Design – Same as A/B soils	Same as A/B Soils	4 $ft.^3$ of volume reduction for every 100 $ft.^2$ of Conservation Area

[1] *Performance achieved toward reducing runoff from a one-inch rainfall.*

[2] *For Conservation Areas with a varying slope, a pro-rated length may be computed only if the first 10 ft. is 2% or less.*

[3] *ELS = Engineered Level Spreader; GD = Gravel Diaphragm*

[4] *Vegetative cover is described in* ***Section SF-4.4***

Table SF-3. Total Pollutant Load Reduction Performance Values for Sheet Flow to Vegetated Filter Strips[1]

Hydrologic Soil Group	**Total Suspended Solids (TSS)**	**Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)[2]**
A / B	TSS = 75%	TP = 50% TN = 50%
C / D	TSS = 63%	TP = 25% TN = 25%
C / D w/ Soil Amendments	TSS = 75%	TP = 50% TN = 50%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration (EMC) as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008).
[2] There is insufficient monitoring data to assign a nutrient removal rate to Filter Strips at this time. Therefore, Sheet Flow to Filter Strips does not receive any nutrient removal credit, and only moderate TSS removal; therefore, nutrient load reduction is a function of runoff volume reduction only.

Table SF-4. Total Pollutant Load Reduction Performance Values for Sheet Flow to Conservation Areas[1]

Hydrologic Soil Group	**Total Suspended Solids (TSS)**	**Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)[2]**
A / B	TSS = 94%	TP = 75% TN = 75%
C / D	TSS = 75%	TP = 50% TN = 50%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration (EMC) as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al (2008).
[2] There is insufficient monitoring data to assign a nutrient removal rate for Conservation Areas at this time. Therefore, Sheet Flow to Conservation Areas does not receive any EMC-based nutrient removal credit, and only moderate EMC-based TSS removal; therefore, nutrient load reduction is a function of runoff volume reduction only.

SF-1.3. Sheet Flow Design Checklist

Table SF-5. Sheet Flow Design Checklist

CHECKLIST

This checklist will help the designer through the necessary design steps for Sheet Flow to Vegetated Filter Strips and Conservation Areas.

- ☐ Check feasibility for site – **Section SF-3**
- ☐ Determine whether a Vegetated Filter Strip or a Conservation Area is applicable to the site – **Tables SF-1 and SF-2**
- ☐ Complete Design Compliance Spreadsheet to plan and confirm required Filter Strip dimensions and if any additional practices are needed to achieve overall site compliance – Design Compliance Spreadsheet & Chapter 3 of Manual
- ☐ Verify Filter Strip sizing guidance and make sure there is an adequate footprint on the site perimeter for Filter Strips or Conservation Areas – **Sections SF-4.1 & SF-4.2**
- ☐ Check design adaptation appropriate to the site – **Section SF-6**
- ☐ Design Filter Strips in accordance with design criteria and typical details –**Sections SF-2 & SF-4**
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading and construction sequence and notes

SF-2. Typical Details

These details show typical configurations for Sheet Flow to a Conservation Area (**Figure SF-4**), pretreatment at the edge of a Conservation Area (**Figure SF-5**), and several configurations and options for engineered level spreaders when inflow is comprised, at least in part, of concentrated flow and/or channel flow (**Figure SF-6 through SF-10**). See Section **SF-4.2** for more detail on engineered level spreaders.

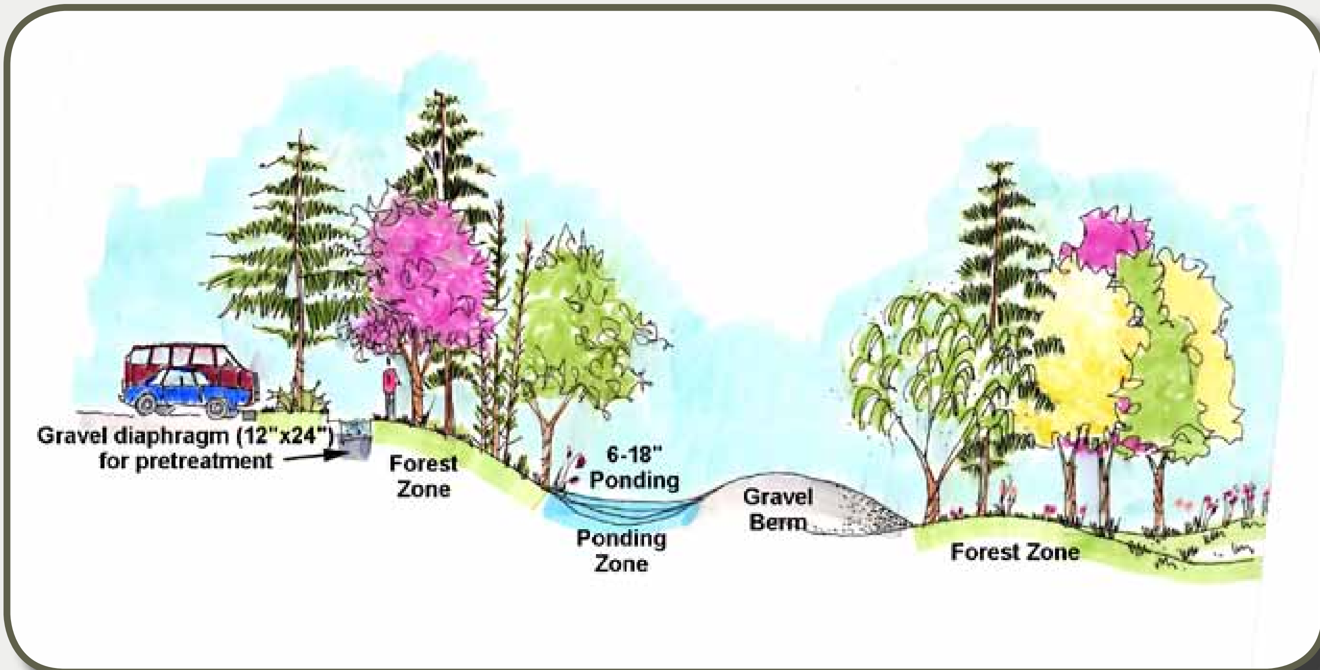


Figure SF-4. Typical Sheet Flow to Conservation Area

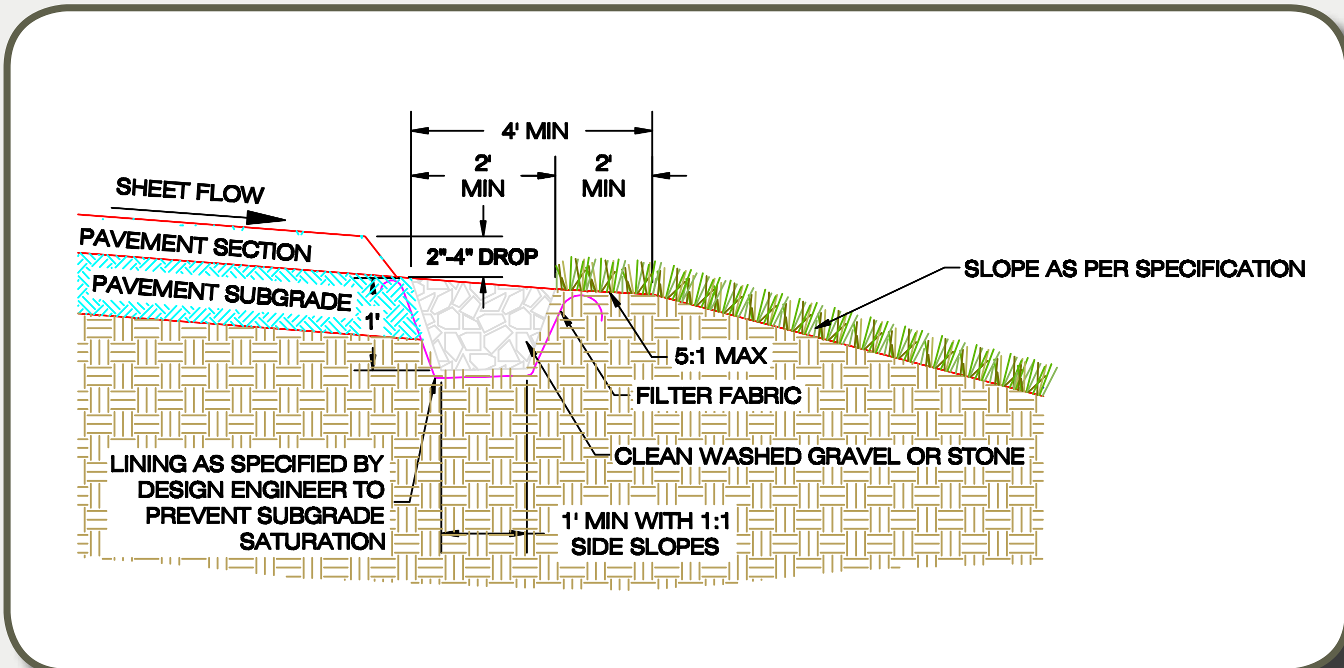


Figure SF-5. Sheet Flow Gravel Diaphragm Pretreatment to Filter Strip or Conservation Area – Typical Section

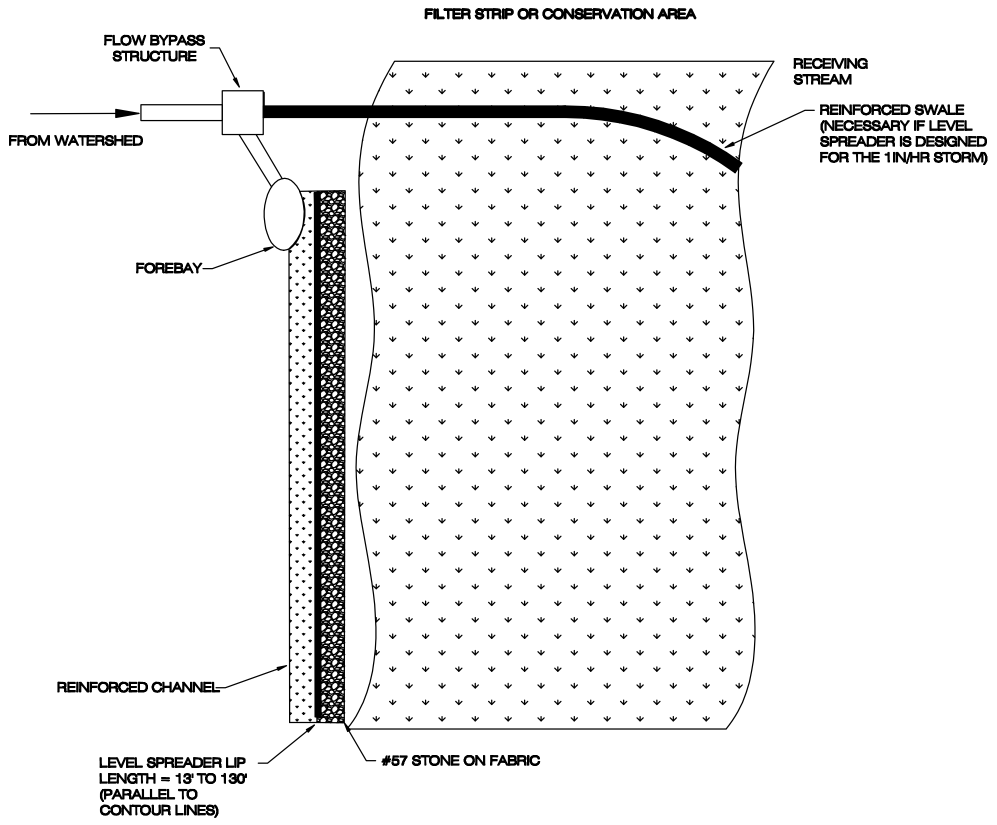


Figure SF-6. Concentrated Flow Engineered Level Spreader (with flow splitter and forebay) to Filter Strip or Conservation Area – Typical Plan View

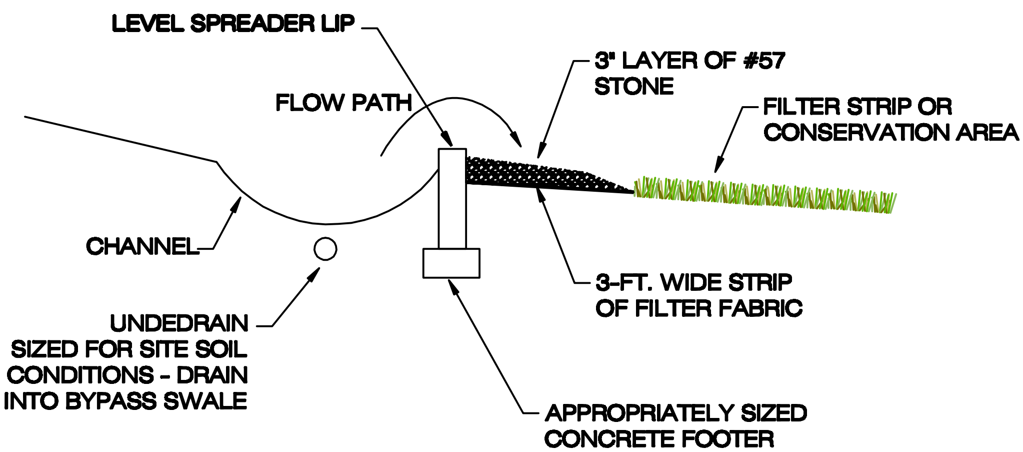


Figure SF-7. Concentrated Flow Engineered Level Spreader to Filter Strip or Conservation Area – Typical Section (Hathaway and Hunt, 2006)

Figure SF-8. Image of Slotted Trench Drain Level Spreader into Conservation Area (Source: CONTECH Construction Products, Inc.)

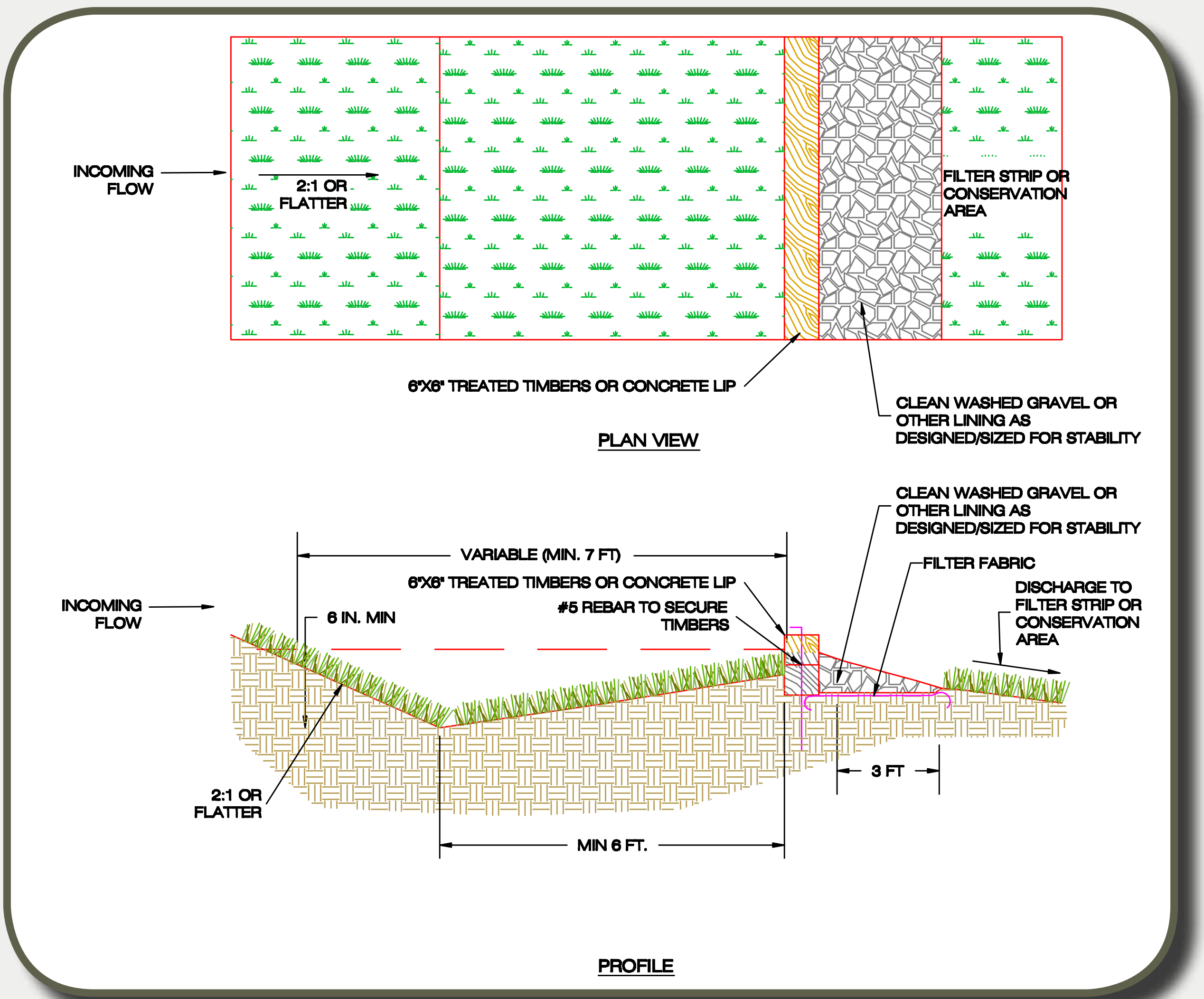


Figure SF-9. Channel Flow Level Spreader to Filter Strip or Conservation Area – Plan View and Section View

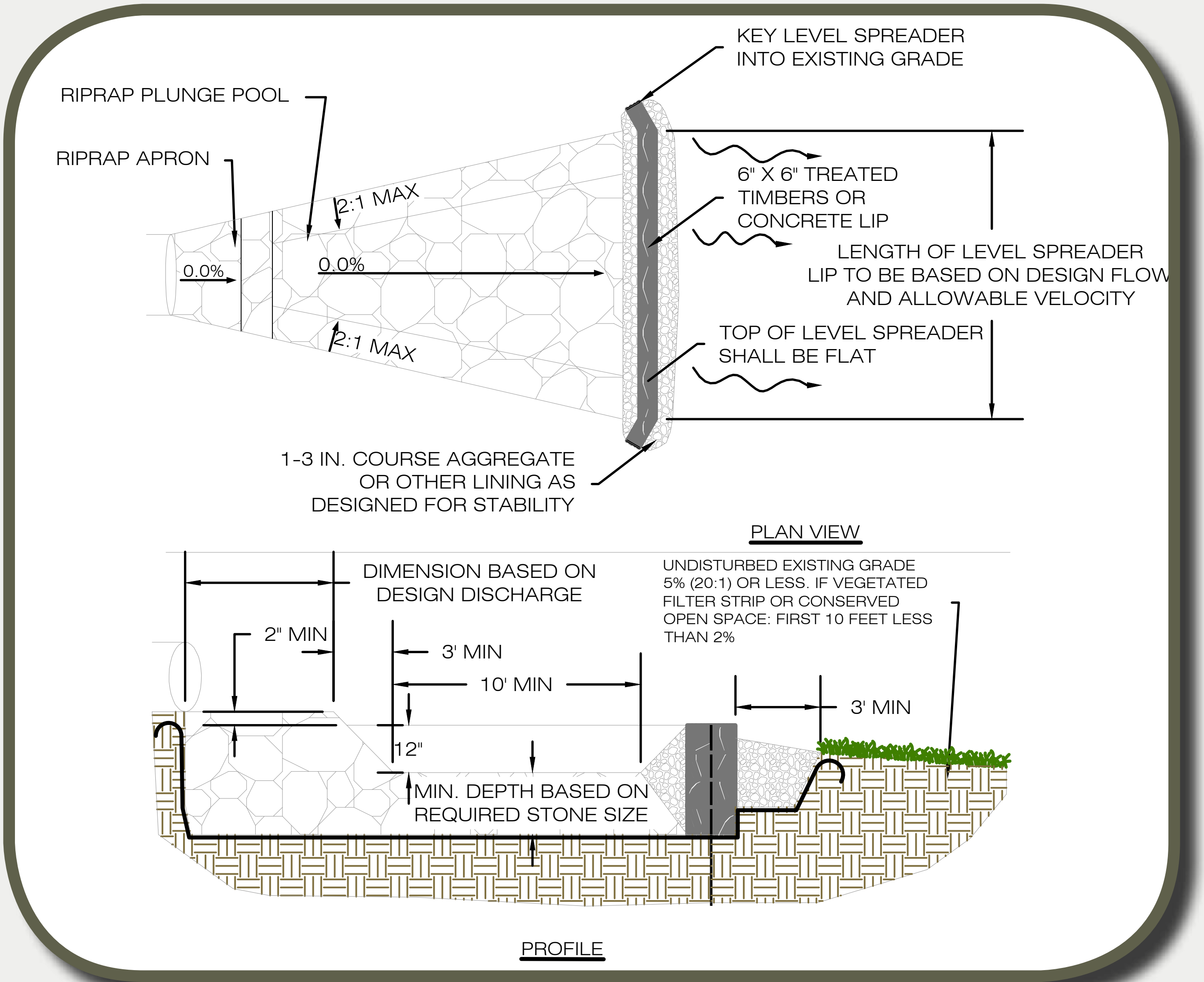


Figure SF-10. Concentrated (Pipe) Inflow Level Spreader to Filter Strip or Conservation Area – Plan and Section (Source: Henrico, Co, VA)

SF-3. Feasibility Criteria and Design Considerations

Vegetated Filter Strips and Conservation Areas can be applied on most sites where adequate space for pervious vegetated areas is available. Highly permeable soils are advantageous and are credited with more runoff reduction; similarly, relatively mild slopes will also improve performance. In cases of tight or moderate soils (HSG C & D soils), Soil Amendments can be added to improve the performance of Vegetated Filter Strips.

Vegetated Filter Strips are also extremely applicable to linear developments such as roads and highways.

SF-3.1. Conservation Areas

The most common design applications of Conservation Areas are on sites that are hydrologically connected to a protected stream buffer, wetland buffer, floodplain, forest Conservation Area, or other protected lands. Conservation Areas are an ideal component of the "outer zone" of stream buffers which normally receives runoff as sheet flow. Care should be taken to locate all energy dissipaters or flow spreading devices outside of the protected area.

Designers may apply a runoff reduction credit to any impervious or managed turf cover that is hydrologically connected and effectively treated by a protected Conservation Area that meets the following eligibility criteria:

- The goal of establishing Conservation Area is to protect a vegetated area contiguous to a receiving system, such as a stream or natural channel, for treating stormwater runoff. Establishing isolated Conservation Area pockets on a development site may not achieve this goal unless they effectively serve to "buffer" the receiving stream from surface runoff to the receiving system. Therefore, a locality may choose to establish goals for minimum acreage to be conserved (in terms of total acreage or percentage of the total project site), and the physical location (adjacent to a stream, or other criteria) in order for the cumulative Conservation Area to qualify for the runoff reduction credit.
- No major disturbance may occur within the Conservation Area during or after construction (i.e., no clearing or grading is allowed except temporary disturbances associated with incidental utility construction, restoration operations, or management of nuisance vegetation). The Conservation Area shall not be stripped of topsoil. Some light grading may be needed at the boundary using tracked vehicles to prevent compaction.
- The limits of disturbance should be clearly shown on all construction drawings and protected by acceptable signage and erosion control measures.
- A long term vegetation management plan must be prepared to maintain the Conservation Area in a natural vegetative condition. Generally, Conservation Area management plans do not encourage or even allow any active management. However, a specific plan should be developed to manage the unintended consequences of passive recreation, control invasive species, provide for tree and understory maintenance, etc. Managed turf is not considered an acceptable form of vegetative management, and only the passive recreation areas of dedicated parkland are eligible for the practice (e.g., the actively used portions of ball fields and golf courses are not eligible), although Conservation Areas can be ideal treatment practices at the edges of turf-intensive land uses.
- The Conservation Area must be protected by a perpetual easement or deed restriction that assigns the responsible party to ensure that no future development, disturbance, or clearing may occur within the area.
- The practice does not apply to jurisdictional wetlands that are sensitive to increased inputs of stormwater runoff (e.g., bogs and fens).

SF-3.2. Key Feasibility Criteria for Filter Strips and Conservation Areas

Available Space. Space requirements for Vegetated Filter Strips vary according to the ground slope and ranges from 35 feet to 65 feet in width (parallel to the flow). Vegetated Filter Strips applied as a runoff reduction practice are smaller in width than those utilized on active construction sites (**Specification 3.25** in WVDEP, 2006). The larger width is required on active construction sites due to the significantly higher anticipated sediment loading. After the development site has been stabilized and the construction has been terminated, the width of the Filter Strip can be reduced to the designated width.

The width of Conservation Areas is similarly dependent on slope and varies from 35 feet to 50 feet or more. The maximum allowable slope, and therefore maximum width, on a Conservation Area is less than that of Filter Strips because the vegetation in Conservation Areas will generally consist of more woody vegetation and not have the thick ground cover to protect the soil from eroding.

The length of Filter Strips or Conservation Areas (perpendicular to the flow) is typically equal to that of the contributing drainage area when runoff enters as sheet flow. When runoff enters as concentrated flow, level spreaders will determine the minimum design length. The length of most Conservation Area applications will be based on the property boundary, stream segment, or other physical feature.

Filter Strips and Conservation Areas are generally applied in two types of situations:

1. The interior of the site where the Filter Strip is applied between the targeted drainage area and the storm drainage conveyance infrastructure (pipe or channel); and
2. The perimeter of the site where vegetated Filter Strips or Conservation Areas manage the runoff as it leaves the site or drains to an offsite conveyance system.

Typical commercial, industrial, or business land uses may not have adequate space for Filter Strips on the interior. Parking islands, landscape areas, and other small pockets of open space are typically better suited for other BMPs, such as bioretention. On the other hand, large institutional campus style developments and large scale residential developments may have numerous opportunities to apply both Filter Strips and Conservation Areas within the proposed infrastructure on the interior of the site. Designers should focus attention on the soil types and slopes when conducting the initial site assessment for the Watershed Protection Elements (see Chapter 2). Three of the Watershed Protection Elements (preserve ecologically sensitive areas; protect trees and other vegetation; and protect native soils) offer opportunities to identify favorable locations for Vegetated Filter Strips and Conservation Areas, both of which can provide very inexpensive and effective runoff reduction and pollutant removal credits.

Designers Should Consider These Practices During Initial Site Assessment

Designers should focus attention on opportunities to implement Vegetated Filter Strips and Conservation Areas when conducting the initial site assessment. This includes permeable soils and flat slopes. Both variants provide very inexpensive and effective runoff reduction and pollutant removal credits.

Site Topography. Filter Strips and Conservation Areas are applicable on sites with rolling or moderate topography. The grade of a proposed Vegetated Filter Strip can be constructed as needed to accommodate the Filter Strip or the overall site design, from 1% to 8% (with the Filter Strip designed accordingly). A minimum of 1% is recommended for any constructed Filter Strips in order to ensure positive drainage, while a Filter Strip designated on natural grade can be as low as 0.5% if allowed by the local plan approving authority. In either case, the first 10 feet must be 2% or less to adequately slow down the runoff as it enters the Filter Strip.

Conservation Areas, on the other hand, are not graded (and actually protected from any impacts during construction), and the designated width of the Conservation Area is determined by the existing grade, ranging from 0.5% to approximately 6% (average slope). Similar to Filter Strips, the first 10 feet must be 2% or less to ensure low velocities. If necessary due to site topography, this 10-foot zone can be constructed as a transition zone upgradient from the Conservation Area in order to achieve the necessary (relatively flat) slope. This is the one exception to Conservation Areas not being graded or disturbed during construction.

Water Table and Bedrock. Filter Strips and Conservation Areas are not constrained by groundwater or bedrock provided these conditions do not impact the growth and health of vegetation.

Soils. Vegetated Filter Strips are appropriate for all soil types, except fill soils. The runoff reduction rate and corresponding pollutant removal, however, are dependent on the underlying HSGs (see **Tables SF-1** through **SF-4** above) and whether soils receive compost amendments.

Soil Amendments on Fill Soils Do Not Achieve the Same Credit

Soil amendments can be applied to fill soils to improve the abstraction and vegetative cover, but will not achieve the runoff reduction credit of C/D soils with soil amendments. Amended fill soils can be credited with the runoff reduction and pollutant removal credit of C/D soils without soil amendments.

Contributing Drainage Area. The contributing drainage area to Vegetated Filter Strips and Conservation Areas is limited by the longest flow path length and not the total acreage (since the total acreage of a linear drainage area is irrelevant when the Filter Strip is applied to the entire length or border). As a rule, flow tends to concentrate after 75 feet of flow length for impervious surfaces, and 150 feet for pervious surfaces (Claytor, 1996). When flow concentrates, it moves too rapidly to be effectively treated by a Filter Strip, unless an engineered level spreader or energy dissipater is used. A perimeter level spreader (such as a gravel diaphragm – **Figure SF-5**) will serve to ensure an even distribution of runoff into the Filter Strip.

When the existing flow at a site is concentrated, a Grass Swale (see **Specification 4.2.5**) and level spreader should be used to disperse the flow into the Filter Strip or Conservation Area.

In cases of Conservation Areas that also serve as stream buffers, the contributing drainage areas can be substantial since the stream or buffer is at the bottom of the contributing drainage area. The runoff will often be conveyed to the Conservation Area by a storm drain or armored channel to protect the slopes from being eroded. Special design considerations must be made to distribute the flow across as wide an area as possible. A level spreader, such as those depicted in **Figures SF-6 through SF-10** must be designed using the design flow of the pipe or drainage system. One alternative is to transition the flow from the pipe or channel with traditional outlet protection and then turn the flow perpendicular to the buffer width into a vegetated channel at a 0% to 0.5% grade, allowing the entire downstream edge of the channel to serve as a level spreader (**Figure SF-6 and SF-9**; also refer to **Specification 3.19** in WVDEP, 2006).

Hotspot Land Uses. Vegetated Filter Strips should not receive hotspot runoff, since the runoff may stress vegetation and/or infiltrated runoff could cause groundwater contamination.

For a list of potential stormwater hotspots, please consult Chapter 6 of the Manual.

Turf-Intensive Land Uses. Both Conservation Areas and Vegetated Filter Strips are appropriate to treat managed turf and the actively-used areas of sports fields, golf courses, parkland, and other turf-intensive land uses (these areas should also be managed by a nutrient management plan that applies to the Vegetated Filter Strip.)

Floodplains. Conservation Areas are acceptable in floodplains. Vegetated Filter Strips should generally be outside of the floodplain and/or buffer areas.

4.2.1. Sheet Flow to Vegetated Filter Strips and Conservation Areas (SF)

SF-4. Design Criteria

The design of Vegetated Filter Strips (and the screening of Conservation Areas) is relatively straightforward in terms of the geometry (dimensions and slope) of the contributing drainage area and the pervious area designated to receive runoff. The additional design elements of improving the performance of marginal soils with Soil Amendments, enhancing the vegetation, and establishing sheet flow with level spreaders are discussed below.

SF-4.1. Soil Amendments

Compost Soil Amendments will enhance the runoff reduction capability of a vegetated Filter Strip when located on Hydrologic Soil Groups (HSG) C and/or D soils, and where necessary, disturbed HSG B soils subject to the following design requirements:

- Approved compost material shall meet the material specifications provided in **Appendix D**.
- The soils in the area of the vegetated Filter Strip should be tested in accordance with **Appendix D** to ascertain pre-construction soil properties at proposed amendment areas (soils verified to be HSG B soils do not necessarily need amendments - the local plan approving authority may require field tests to verify the HSG of the soil in order to approve the use of the runoff reduction credit without amendments). Testing will also confirm or characterize any potential drainage problems and determine what, if any, further soil amendments may be needed.
- The compost amendments should extend over the full length and width of the Filter Strip.
- The amount of approved compost material and the depth to which it must be incorporated is provided in **Table SF-6** (and discussed further in **Appendix D**).
- The amended area will be raked to achieve the most level slope possible without using heavy construction equipment, and it will be stabilized rapidly with perennial grass and/or herbaceous species.
- If slopes exceed 3%, a protective biodegradable fabric or matting (e.g., **Specification 3.13** in WVDEP, 2006) should be installed to stabilize the site prior to runoff discharge.
- Compost amendments should not be incorporated until the gravel diaphragm and/or engineered level spreader are installed (see Section SF-7.2).
- The local plan approval authority may require compost amendments on disturbed HSG B soils in order to receive credit as a vegetated Filter Strip unless the designer can provide verification of the adequacy of the disturbed soil type, texture, and profile to function as a Filter Strip.

Table SF-6. Short-Cut Method to Determine Compost and Incorporation Depths

	Contributing Impervious Cover (IC) to Soil Amendment (SA) Area Ratio [1]			
	IC/SA = 0 [2]	IC/SA = 0.5	IC/SA = 0.75	IC/SA = 1.0 [3]
Compost (in) [4]	4	6	8	10
Incorporation Depth (in)	8	12	16	18 to 24
Incorporation Method	Rototiller	Tiller	Subsoiler	Subsoiler

Notes:
[1] *IC = contributing impervious cover (sq. ft.) and SA = surface area of compost amendment (sq. ft.)*
[2] *For amendment of compacted lawns that do not receive off-site runoff*
[3] *In general, IC/SA ratios greater than 1 should be avoided*
[4] *Average depth of compost added*

Once the area and depth of the soil amendments are known, the designer can estimate the total amount of compost needed, using an estimator developed by TCC (1997):

$$C = A * D * 0.0031$$

Where: C = compost needed (cu. yds.)
A = area of soil amended (sq. ft.)
D = depth of compost added (in.)
0.0031 = unit conversion factor

SF-4.2. Pretreatment: Diaphragms, Berms and Level Spreaders

Gravel Diaphragms: A pea gravel diaphragm at the top of the slope is required for both Conservation Areas and Vegetated Filter Strips that receive sheet flow. The pea gravel diaphragm is created by excavating a two-foot wide and one-foot deep trench that runs on the same contour at the top of the Filter Strip. The diaphragm serves two purposes. First, it acts as an energy dissipating 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. Refer to **Figure SF-5**.

- The flow should travel over the impervious area and to the practice as sheet flow and then drop 2 to 4 inches onto the gravel diaphragm. The drop helps to prevent runoff from running laterally along the pavement edge, where grit and debris tend to build up (thus allowing by-pass of the Filter Strip).
- A layer of filter fabric should be placed between the gravel and the underlying soil trench.
- If the contributing drainage area is steep (6% slope or greater), larger stone (clean bank-run gravel that meets AASHTO #57 grade – blend of # 5, 6, & 7) should be used in the diaphragm.
- If the contributing drainage area is solely turf (e.g., sports field), then the gravel diaphragm may be eliminated.

Engineered Level Spreaders. The design of engineered level spreaders should conform to the following design criteria based on recommendations of Hathaway and Hunt (2006), or a locally approved standard that meets the intent of these criteria, in order to ensure non-erosive sheet flow into the vegetated buffer area. **Figures SF-6, SF-7, SF-8 and SF-9** represent level spreader configurations. **Figure SF-6** includes a bypass structure that diverts the design storm to the level spreader, and bypasses the larger storm events around the Conservation Area or Vegetated Filter Strip through an improved channel.

An alternative approach is a modified **Specification 3.17** from WVDEP (2006) outlet protection design depicted in **Figure SF-8** where pipe or channels discharge at the landward edge of a floodplain or stream buffer. The entire flow is directed through a stilling basin energy dissipater and then a level spreader such that the entire design storm for the conveyance system (typically a 10-year frequency storm) is discharged as sheet flow through the buffer. Also refer to Henrico County's Environmental Program Manual, Chapter 9, Minimum Design Standard 9.01 "Energy Dissipater" at: http://www.co.henrico.va.us/works/environmental-manual.html.

Key design elements of the engineered level spreader, as provided in **Figures SF-6 through SF-9**, include the following:

- High flow bypass provides safe passage for larger design storms through the Filter Strip. The bypass channel should accommodate all peak flows greater than the water quality design flow.
- A forebay should have a maximum depth of 3 feet and gradually transition to a depth of 1 foot at the level spreader lip (**Figure SF-6**). The forebay is sized such that the surface area is 0.2% of the contributing impervious area (a forebay is not necessary if the concentrated flow is from the outlet of an extended detention basin or similar practice).
- The length of the level spreader should be determined by the type of filter area and the design flow:
    - o 13 feet of level spreader length per every 1 cfs of inflow for discharges to a Vegetated Filter Strip or Conservation Area consisting of native grasses or thick ground cover;
    - o 40 feet of level spreader length per every 1 cfs of inflow when the spreader discharges to a Conservation Area

consisting of forested or reforested buffer (Hathaway and Hunt, 2006).
- o Where the Conservation Area is a mix of grass and forest (or re-forested), establish the level spreader length by computing a weighted average of the lengths required for each vegetation type.
- o The minimum level spreader length is 13 feet and the maximum is 130 feet.
- o For the purposes of determining the Level Spreader length, the peak discharge shall be determined using the Modified Curve Number Method, described in **Appendix E**.

- The level spreader lip should be concrete, wood or other non-erodible material with a well-anchored footer.
- The ends of the level spreader section should be tied back into the slope to avoid scouring around the ends of the level spreader; otherwise, short-circuiting of the facility could create erosion.
- The width of the level spreader channel on the up-stream side of the level lip should be three times the diameter of the inflow pipe, and the depth should be 9 inches or one-half the culvert diameter, whichever is greater.
- The level spreader should be placed 3 to 6 inches above the downstream natural grade elevation to avoid turf buildup. In order to prevent grade drops that re-concentrate the flows, a 3-foot long section of AASHTO # 3 stone, underlain by filter fabric, should be installed just below the spreader to transition from the level spreader to natural grade.
- Vegetated receiving areas down-gradient from the level spreader must be able to withstand the force of the flow coming over the lip of the device. It may be necessary to stabilize this area with temporary or permanent rolled erosion control products (**Specification 3.13** in WVDEP, 2006) in accordance with the calculated velocity (on-line system peak, or diverted off-line peak) and material specifications, along with seeding and stabilization in conformance with the West Virginia Erosion and Sediment Control Manual.

Permeable Berm: Vegetated Filter Strips should be designed with a permeable berm at the toe of the Filter Strip to create a shallow ponding area. Runoff ponds behind the berm and gradually flows through outlet pipes in the berm or through a gravel lens in the berm with a perforated pipe. During larger storms, runoff may overtop the berm (Cappiella et al., 2006). The permeable berm should have the following properties:

- A wide and shallow trench, 6 to 12 inches deep, should be excavated at the upstream toe of the berm, parallel with the contours.
- Media for the berm should consist of 40% excavated soil, 40% sand, and 20% pea gravel.
- The 6 to 12 inch high berm should be located downgradient of the excavated depression and should have gentle side slopes to promote easy mowing (Cappiella et al., 2006).
- Stone may be needed to armor the top of berm to handle extreme storm events.
- A permeable berm is not needed when Vegetated Filter Strips are used as pretreatment to another stormwater practice.

SF-4.3. Conveyance and Overflow

Vegetated Filter Strips and Conservation Areas are generally considered on-line practices (refer to **Chapter 3** for definition of on-line and off-line practices). The limitations on the contributing drainage area for sheet flow applications will minimize the need for large storm conveyance and overflow provisions. However, in cases where inflow is from a pipe or channel and must be converted to sheet flow, the Filter Strip or Conservation Area can be taken off-line by using a diversion structure in conjunction with the level spreader. The goal is to prevent the conveyance system design storm discharge (usually the 10-year storm peak rate) from scouring a channel or rill through the practice. **Figure SF-6** plan view shows a diversion structure in conjunction with a level spreader.

SF-4.4. Vegetation

Conservation Areas. No grading or clearing of native vegetation is allowed within the Conservation Area unless it is in compliance with an invasive species management plan or a vegetation enhancement plan. In general, an operation and management plan for maintaining a healthy vegetative cover should be developed for the property and approved by the plan approving authority as conditions of the easements and runoff reduction credits.

Reforested Conservation Areas. At some sites, the proposed stream buffer or Conservation Area may be in turf or meadow cover, or overrun with invasive plants and vines. In these situations, a landscape architect or horticulturalist should prepare a reforestation or restoration plan. The entire area can be planted with native trees and shrubs or planted to achieve a gradual transition from turf to meadow to shrub and forest. Trees and shrubs with deep rooting capabilities are recommended for planting to maximize soil infiltration capacity. Over-plant with seedlings for fast establishment and to account for mortality. Plant larger stock at desired spacing intervals (25 to 40 feet for large trees) using random spacing (Cappiella et al., 2006). Plant ground cover or a herbaceous layer to ensure rapid vegetative cover of the surface area.

Vegetated Filter Strips. Vegetated Filter Strips should be planted at such a density to achieve a 90% grass/herbaceous cover after the second growing season. Filter Strips should be seeded, not sodded. Seeding establishes deeper roots, and sod may have muck soil that is not conducive to infiltration (Wisconsin DNR, 2007). The Filter Strip vegetation may consist of turf grasses, meadow grasses, other herbaceous plants, shrubs, and trees, as long as the primary goal of at least 90% coverage with grasses and/or other herbaceous plants is achieved. Designers should choose vegetation that stabilizes the soil and is salt tolerant. Vegetation at the toe of the filter, where temporary ponding may occur behind the permeable berm, should be able to withstand both wet and dry periods. The planting areas can be divided into zones to account for differences in inundation and slope.

SF-4.5. Signage

Signage is a valuable maintenance tool since landscaping contractors may not be aware of the designation of pervious areas specifically designed Filter Strips. There are numerous examples of pretreatment swales and vegetated Filter Strips being managed with pesticides and fertilizers along with the rest of the managed turf on a site, which may be prevented by installing signage at the site.

Signage indicating the designation of Conservation Areas is mandatory to ensure that current and future owners are aware of the designation (in addition to all the appropriate legal documentation that is conveyed with the property) and the accompanying operation and management plan.

4.2.1. Sheet Flow to Vegetated Filter Strips and Conservation Areas (SF)

SF-5. Materials Specifications

Recommended material specifications for Vegetated Filter Strips and Conservation Areas are shown in **Table SF-7**.

Table SF-7. Vegetated Filter Strip and Conservation Area Materials Specifications

Material	Specification	Quantity
Gravel Diaphragm	Pea Gravel (AASHTO #8 or ASTM equivalent) or where steep (6% +) use clean bank-run AASHTO #57 or ASTM equivalent (1-inch maximum).	Diaphragm should be 2 ft. wide, 1 ft. deep, and at least 3 in. below the edge of pavement.
Permeable Berm	40% excavated soil, 40% sand, and 20% pea gravel to serve as the media for the berm.	
Geotextile	Needled, non-woven, polypropylene geotextile meeting the following specifications: Grab Tensile Strength (ASTM D4632): > 120 lbs. Mullen Burst Strength (ASTM D3786): > 225 lbs./sq. in. Flow Rate (ASTM D4491): > 125 gpm/sq. ft. Apparent Opening Size (ASTM D4751): US #70 or #80 sieve	
Engineered Level Spreader	Level Spreader lip should be concrete, timber, or other rigid material; Reinforced channel on upstream of lip: Specification 3.13 in WVDEP (2006): Rolled Erosion Control Products (biodegradable or permanent if warranted by velocities) See Hathaway and Hunt (2006) or Henrico County Environmental Program Manual (Henrico County, no date), or WVDEP (2006).	
Erosion Control Fabric or Matting	Where flow velocities dictate, use woven biodegradable erosion control fabric or mats that are durable enough to last at least two growing seasons Specification 3.13 in WVDEP, 2006).	
Topsoil	If existing topsoil is inadequate to support dense turf growth, imported top soil (loamy sand or sandy loam texture), with less than 5% clay content, corrected pH at 6 to 7, a soluble salt content not exceeding 500 parts per million, and an organic matter content of at least 2% shall be used. Topsoil shall be uniformly distributed and lightly compacted to a minimum depth of 6 to 8 inches.	
Compost	Compost shall be derived from plant material and provided by a member of the U.S. Composting Seal of Testing Assurance program, as outlined in **Appendix D**.	

SF-6. Design Adaptations

SF-6.1. Karst Terrain

Conservation Area areas are highly recommended in karst terrain, particularly when storm flow discharges to the outer boundary of a karst protection area (see CSN, 2009).

Vegetated Filter Strips can also be used to treat runoff from small areas of impervious cover (e.g., less than 5,000 square feet).

In no case should the use of Vegetated Filter Strips or Conservation Areas be considered as a replacement for an adequate receiving system for developed-condition stormwater discharges, unless the adequacy of the design has been demonstrated as consistent with good engineering practice, design sources for karst terrain (such as CSN, 2009), and the local plan approving authority.

SF-6.2. Linear Highway Sites

Vegetated Filter Strips are highly recommended to treat highway runoff if the median and/or road shoulder is wide enough to provide an adequate flow path.

SF-6.3. Stormwater Retrofitting

Vegetated Filter Strips and Conservation Areas are versatile practices for retrofitting. Some of the chief considerations for retrofitting are accounting for the current use and/or condition of pervious areas and determining if they can be successfully re-designated as a runoff management practice.

For more information on retrofitting, see the Center for Watershed Protection's manual, Urban Stormwater Retrofit Practices (Schueler et al., 2007).

SF-7. Construction and Installation

SF-7.1. Construction Sequence for Conservation Areas

The Conservation Areas must be fully protected during the construction stage of development and kept outside the limits of disturbance on the Erosion and Sediment (E&S) Control Plan.

- No clearing, grading or heavy equipment access is allowed except temporary disturbances associated with incidental utility construction, restoration operations or management of nuisance vegetation.
- The perimeter of the Conservation Area shall be protected by super silt fence, chain link fence, orange safety fence, or other measures to prevent sediment discharge and access by construction equipment.
- The limits of disturbance should be clearly shown on all construction drawings and identified and protected in the field by acceptable signage, silt fence, snow fence or other protective barrier.
- Construction of the gravel diaphragm or engineered level spreader shall not commence until the contributing drainage area has been stabilized and perimeter E&S controls have been removed and cleaned out.
- Some light grading may be needed at the Conservation Area boundary; this should be done with tracked vehicles to prevent compaction.
- Stormwater should not be diverted into the Conservation Area until the gravel diaphragm and/or level spreader are installed and stabilized.

SF-7.2. Construction Sequence for Vegetated Filter Strips

Vegetated Filter Strips can be within the limits of disturbance during construction. The following procedures should be followed during construction:

- Before site work begins, vegetated Filter Strip boundaries should be clearly marked.
- Only vehicular traffic used for Filter Strip construction should be allowed within 10 feet of the Filter Strip boundary (City of Portland, 2004).
- If existing topsoil is stripped during grading, it shall be stockpiled for later use.
- Construction runoff should be directed away from the proposed Filter Strip site, using perimeter silt fence, or, preferably, a diversion dike.
- Construction of the gravel diaphragm or engineered level spreader shall not commence until the contributing drainage area has been stabilized and perimeter E&S controls have been removed and cleaned out.
- Vegetated Filter Strips require light grading to achieve desired elevations and slopes. This should be done with tracked vehicles to prevent compaction. Topsoil and or compost amendments should be incorporated evenly across the Filter Strip area, stabilized with seed, and protected by biodegradable erosion control matting or blankets.
- Stormwater should not be diverted into the Filter Strip until the turf cover is dense and well established.

SF-7.3. Construction Inspection

Construction inspection is critical to obtain adequate spot elevations, to ensure the gravel diaphragm and/or engineered level spreader is completely level, on the same contour, and constructed to the correct design elevation. As-built surveys should be required to ensure compliance with design standards. Inspectors should evaluate the performance of the Filter Strip after the first big storm to look for evidence of gullies, outflanking, undercutting or sparse vegetative cover. Spot repairs should be made, as needed.

An example construction phase inspection checklist is available in Appendix A.

SF-8. Maintenance Criteria

SF-8.1. Maintenance Agreements

Maintenance agreements must be executed between the owner and the local authority. The agreements will specify the property owner's primary maintenance responsibilities and authorize local agency staff to access the property for inspection or corrective action in the event that proper maintenance is not preformed.

All Filter Strips must be covered by a drainage easement or other documentation to allow inspection and maintenance by local authority staff. If the filter area is a natural Conservation Area, it must be protected by a perpetual easement or deed restriction that assigns the responsible party to ensure that no future development, disturbance or clearing may occur within the area, except as stipulated in the vegetation maintenance plan.

When Filter Strips and Conservation Areas are applied on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to modified maintenance agreements as described above.

Maintenance of these areas should be integrated into routine landscape maintenance tasks. If landscaping contractors will be expected to perform maintenance, their contracts should contain specifics on unique or in the case of Conservation Areas, minimal, landscaping needs.

Maintenance tasks and frequency will vary depending on the size and location of the landscaping template chosen, and the type of surface cover in the practice. A generalized checklist of common maintenance tasks is provided in **Appendix A** of the Manual.

SF-8.2. Maintenance Inspections

Annual inspections are used to trigger maintenance operations such as sediment removal, spot re-vegetation and level spreader repair. Ideally, inspections should be conducted in the non-growing season when it easier to see the flow path. As noted above, example maintenance inspection checklists for sheet flow to a Filter Strip or Conservation Area are found in **Appendix A**.

Inspections should include the following items:

- Flow does not short-circuit the Filter Strip;
- Debris and sediment have not built up at the top of the Filter Strip;
- Foot or vehicular traffic does not compromise the gravel diaphragm;
- Scour and erosion do not occur within the Filter Strip;
- Sediments are cleaned out of level spreader, forebays and flow splitters; and
- Vegetative density exceeds a 90% cover in the boundary zone or grass filter.

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ID-1. Introduction

Impervious Surface Disconnection involves managing runoff close to its source by intercepting, infiltrating, filtering, treating or reusing it as it moves from the impervious surface to the drainage system. Disconnection practices can be used to reduce the volume of runoff that enters the combined or separate sewer systems.

Impervious Surface Disconnection can be used to:

- Partially manage the first one-inch of rainfall from impervious cover on-site when applying Simple Disconnection in all Hydrologic Soil Groups (HSGs), with or without Soil Amendments (see **Table ID-1**)
- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs) (See **Table ID-2**)
- Retrofit existing developed areas

Two kinds of disconnection are provided:

(1) **Simple Disconnection**, whereby rooftops and/or on-lot residential impervious surfaces are directed to pervious areas or conservation areas, on lots/parcels that are generally 6,000 square feet or more (depending on local conditions), and (2) **Disconnection with Compensatory Practices**, where adequate space for simple disconnection is not available, or a higher volume reduction credit is desired. Compensatory (micro-scale) runoff reduction practice(s) can be applied immediately adjacent to the rooftop downspout or impervious surface. Compensatory Practices can use less space than Simple Disconnection and can enhance runoff reduction rates.

Disconnection with Compensatory Practices include:

- Infiltration by small infiltration practices (dry wells or french drains, see **Specification 4.2.6. Infiltration**)
- Filtration or extended filtration by rain gardens or stormwater planters (see **Specification 4.2.3. Bioretention**)
- Storage and reuse with a cistern or other vessel (rainwater harvesting) (see **Specification 4.2.8. Rainwater Harvesting**)

Both types of disconnection are applicable to residential scale projects or small commercial rooftops (similar in size to residential). More highly impervious and/or commercial applications should use the other best management practices (BMPs) in this Manual.

Figure ID-1 further illustrates typical Impervious Surface Disconnection applications. **Figure ID-2** is a schematic of a typical rooftop disconnection to compensatory practices. **Tables ID-1** and **ID-2** describe two levels of disconnection design and associated volume reduction and pollutant removal performance rates. **Table ID-3** is a design checklist to help guide the design process for disconnection practices.

ID-1.1. Planning This Practice

Figure ID-1. Typical Applications of Impervious Surface Disconnection

Simple Rooftop Disconnection

Simple Rooftop Disconnection with Soil Amendments

Disconnection with Compensatory Practice:
Small-Scale Infiltration
(Source : http://www.brickstoremuseum.org/campaign_timeline.shtml)

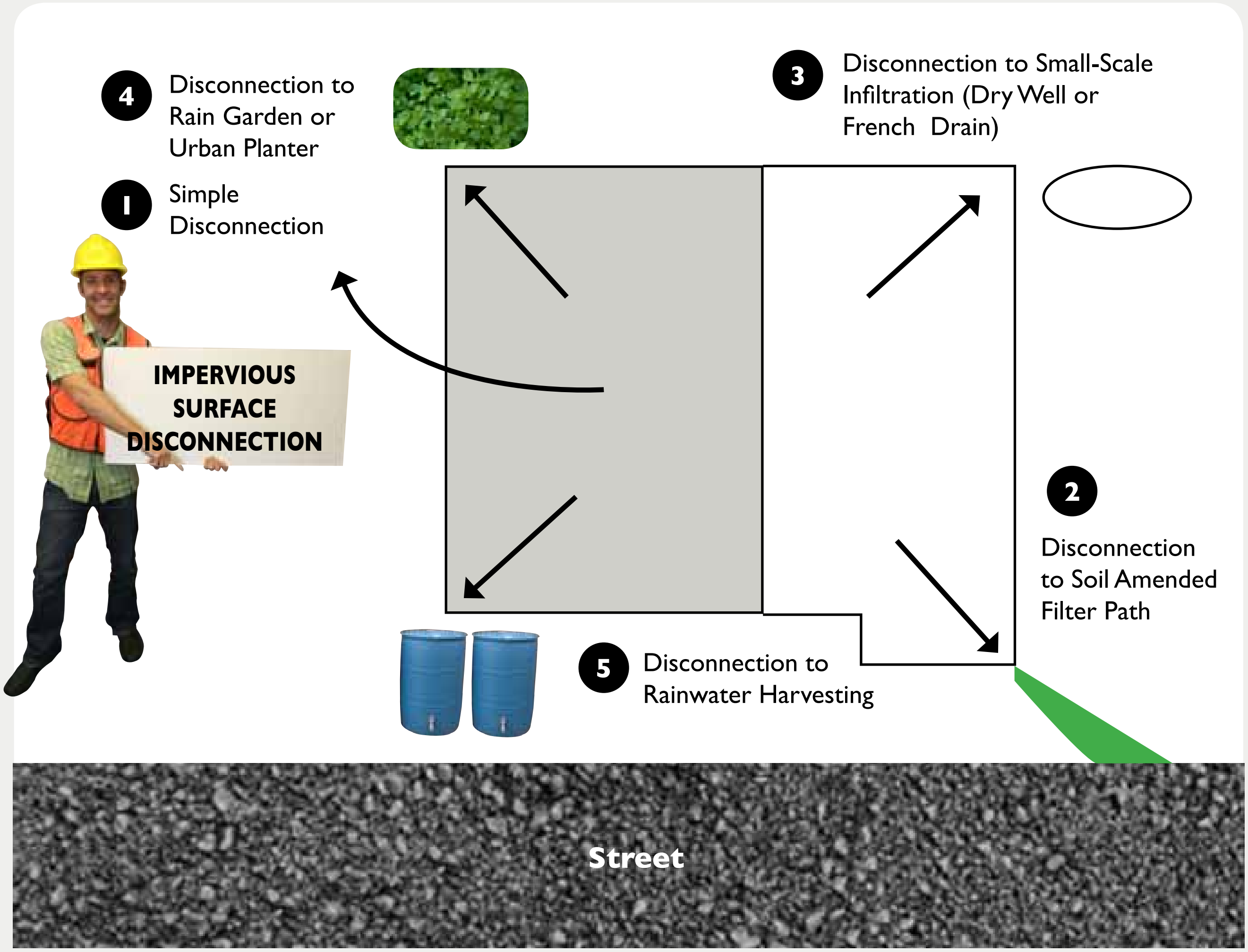
Disconnection with Compensatory Practice:
Residential Rain Gardens

Disconnection with Compensatory Practice: Urban Planter (Source: U.S. EPA)

Disconnection to Rainwater Harvesting Apparatus Cistern (Source: U.S. EPA)

Disconnection to Rainwater Harvesting Apparatus Rain Barrel (Source: U.S. EPA)

Figure ID-2. Roof Disconnection with Compensatory Runoff Reduction Practices



(Source for base graphic: Schueler et al., 2007)

1. Simple impervious disconnection – Table ID-1 & Section ID-4.1
2. Disconnection to Soil Amended Filter Path – Section ID-4.2 & Appendix D
3. Disconnection to Small-Scale Infiltration – Section ID-4.3
4. Disconnection to Rain Garden or Urban Planter – Section ID-4.4
5. Disconnection to Rainwater Harvesting – Section ID-4.5

ID-1.2. Impervious Surface Disconnection Design Options & Performance

Table ID-1 describes the design options for Simple Disconnection and Disconnection with Compensatory Practices, and the practice performance in terms of reducing the volume associated with one inch of rainfall on the site. **Table ID-2** summarizes pollutant removal performance values for Simple Disconnection based on the site soil profile. This is for the purpose of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans. Performance credits for Disconnection with Compensatory Practices vary by design and site conditions. See Section ID-4 for sizing details.

Table ID-1. Impervious Surface Disconnection: Descriptions & Performance

Hydrologic Soil Group	Description	Applications[1]	Performance[2]
A / B	**Simple Disconnection** • Max. 1,000 sq. ft. rooftop area to each disconnection point • Non-rooftop impervious area longest flow path ≤ 75 ft. • Disconnection area width: ≥15 ft. / ≤ 25 ft. • Disconnection area length: = 40 ft. [3] • Grade of receiving pervious area ≤ 2%; or ≤ 5% with turf reinforcement	• Residential or small commercial rooftops and/or other small areas of on-lot impervious cover; • Lot sizes ≥ 6,000 sq. ft. (this is a recommended lot size for Simple Disconnection; local governments may determine a locally-appropriate size. Smaller lots can still disconnect to Compensatory Practice)	4 cu. ft. of volume reduction for every 100 sq. ft. of pervious receiving area.
C / D	**Simple Disconnection** • Same design criteria as above	• See above	2 cu. ft. of volume reduction for every 100 sq. ft. of pervious receiving area.
C / D	**Soil Amendments[4]** • Same design criteria as above • Soils of pervious receiving area amended as per specifications	• See above	4 cu. ft. of volume reduction for every 100 sq. ft. of pervious receiving area

Hydrologic Soil Group	Description	Applications[1]	Performance[2]
Any Soil Group[4]	**Compensatory Practices[5]:** • Infiltration • Rain Garden • Rainwater Harvesting	• Residential or small commercial rooftops or on-lot impervious cover; • Lot sizes may vary[6]	Varies[7]

[1] Disconnection is applicable in residential applications and small areas of imperviousness in commercial/office settings.
[2] Performance achieved toward reducing one inch of rainfall
[3]Disconnection receiving area is limited since credit is measured as "per 100 sq. ft." of receiving area.
[4]Refer to Section ID-4.2 and Appendix D *for Soil Amendments*
[5]Refer to Section ID-4 *for feasibility, limitations, and design elements for compensatory Practices.*
[6] Compensatory Practices are often applied on lots that are smaller and therefore do not have the space for the Simple Disconnection practices and/or the soils are not suitable.
[7]The runoff reduction performance credits for the Compensatory Practices vary by design and site conditions. See Section ID-4 *for sizing details.*

Table ID-2. Total Pollutant Load Reduction Performance Values for Impervious Surface Disconnection[1]

Hydrologic Soil Groups	Total Suspended Solids (TSS)	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)[2, 3]
A & B	TSS = 75%	TP = 50% TN = 50%
C & D	TSS = 63%	TP = 25% TN = 25%

[1] Performance values for the Compensatory Practices vary by design and site conditions. See Section 4 *for sizing details.*
[2] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008).
[3] There is insufficient monitoring data to assign a nutrient removal rate for Simple Disconnection at this time. Therefore, Simple Disconnection does not receive any nutrient removal credit, and only moderate TSS removal; therefore, nutrient load reduction is a function of runoff volume reduction only.

ID-1.3. Impervious Surface Disconnection Design Checklist

Table ID-3. Impervious Surface Disconnection Design Checklist

CHECKLIST

This checklist will help the designer through the necessary design steps for Impervious Surface Disconnection.

- ☐ Check feasibility for site: lot size, soils, slope, etc. – **Section ID-3**
- ☐ Determine if Simple Disconnection is applicable, or if Compensatory Practices are necessary – **Section ID-3**
- ☐ Complete Design Compliance Spreadsheet to plan and confirm Simple Disconnection or Disconnection with Compensatory Practices, and additional practices as needed for overall site compliance – **Chapter 3, Section 3.4.4**
- ☐ Check practice sizing guidance and verify that adequate footprint is available at each downspout or disconnection location – **Section ID-4**
- ☐ Check design adaptation appropriate to the site – **Section ID-6**
- ☐ Design Simple Disconnection or Disconnection with Compensatory Practices in accordance with design criteria and typical details – **Sections ID-2 and ID-4**
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence and notes – **Section ID-2 and ID-4**

4.2.2. Impervious Surface Disconnection (ID)

ID-2. Typical Details

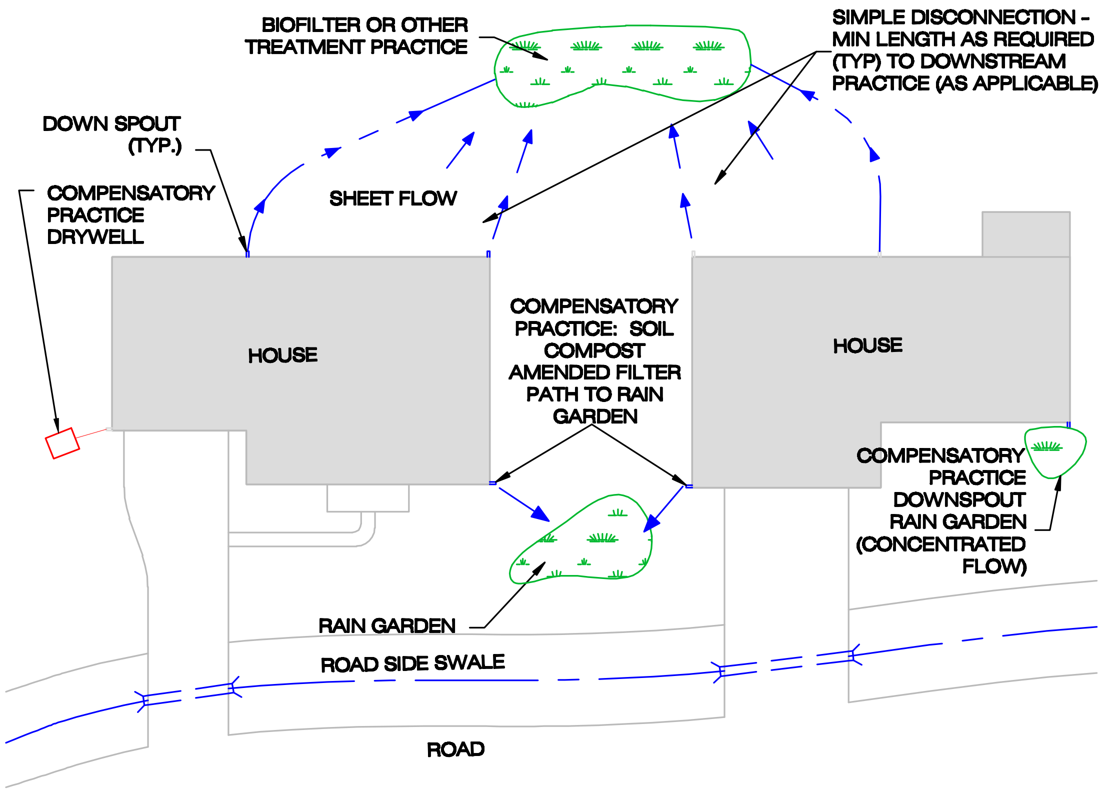


Figure ID-3. Example of Impervious Disconnection Options for Residential Rooftop: Plan View

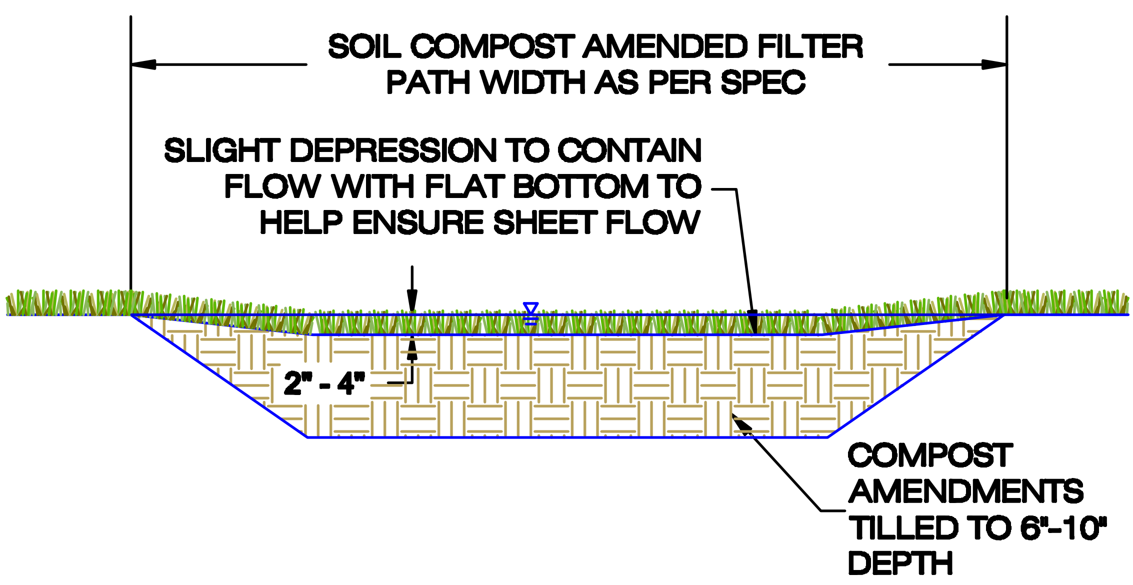


Figure ID-4. Simple Disconnection with Soil Compost Amended Filter Path

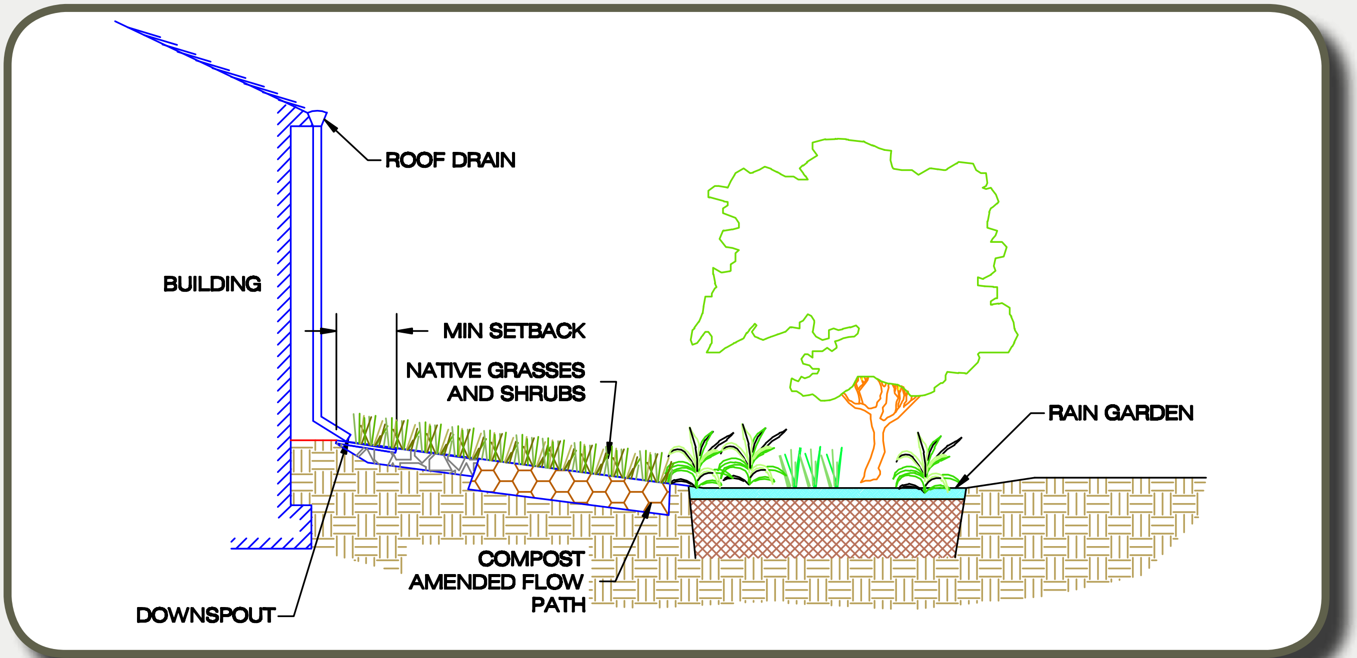


Figure ID-5. Example of Residential Disconnection with Compost Amended Flow Path to Downstream Rain Garden

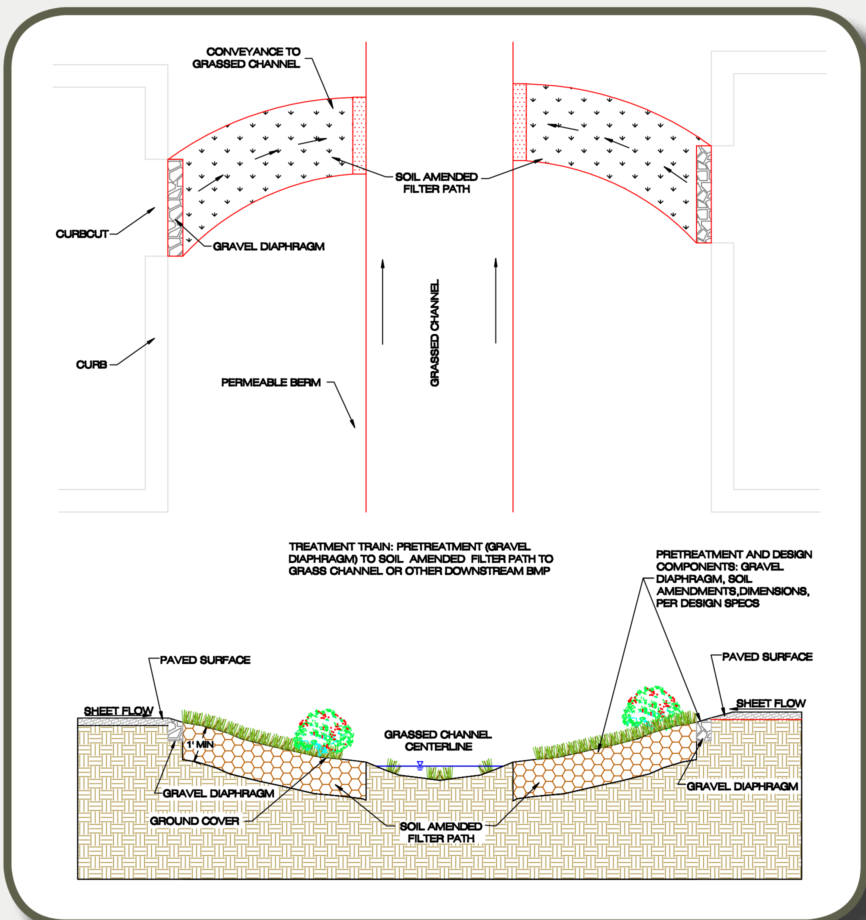


Figure ID-6. Disconnection of Small Impervious Area (e.g., ¼ acre or less): Soil Amended Filter Path to Downstream Grass Channel (or other treatment): Example of Disconnection as Part of Treatment Train

4.2.2. Impervious Surface Disconnection (ID)

ID-3. Feasibility Criteria and Design Considerations

Impervious Surface disconnections are ideal for use on residential single family developments. Simple Disconnection can be applied to roof drains, driveways, and other small scale impervious areas on individual residential lots. Simple Disconnection becomes gradually more difficult to apply as the overall density and scale of impervious cover increases. Commercial, institutional, municipal, and multi-family residential developments will appear to have pervious areas throughout the development footprint; however, the maximum contributing drainage area and the various design requirements for simple disconnection often limit its use on these developments.

Disconnection with a Compensatory Practice is intended to address the limitations of available space or soils that are common on multi-family residential and non-residential development projects. Disconnection to a Compensatory Practice still relies on a relatively simple design that employs sheet flow through a pervious area to the downstream practice. For larger areas of impervious cover (generally greater than 2,500 square feet) the designer should employ the other stand-alone specifications in this Manual.

Use the Other BMPs in This Manual for Larger (generally greater than 2,500 square feet) Multi-Family, Commercial, or Institutional Rooftops & Other Areas of Impervious Cover

Impervious Surface Disconnection is intended for residential lots and small areas of impervious cover at commercial or institutional development sites. Often, the practice can be used as part of a treatment train in conjunction with other downstream practices. However, Impervious Surface Disconnection is NOT intended to be a stand-alone BMP for larger areas of impervious cover.

Feasibility criteria and design considerations for Impervious Surface Disconnection are provided in this section. The designer is encouraged to refer to the Feasibility Criteria and Design Consideration sections for the individual Compensatory Practices for more detailed information:

- Infiltration: Specification 4.2.6
- Water Quality Swale: Specification 4.2.3.A
- Urban Bioretention: Specification 4.2.3.B
- Residential Rain Gardens: Specification 4.2.3.C
- Rainwater Harvesting (Cisterns): Specification 4.2.8

Feasibility criteria and design considerations for Simple Disconnection include the following:

Available Space. Simple Disconnection is generally not advisable for residential lots less than 6,000 square feet in area, although it is likely possible to employ one of the runoff reduction Compensatory Practices on smaller lots (e.g., cistern, infiltration, etc.). The available disconnection area must be at least 15 feet wide and 40 feet long. The disconnection width is limited to 25 feet. Concentrated flow must be converted to sheet flow across the entire width with a level spreader at the entrance to the disconnection area.

Site Topography. Simple Disconnection is best applied when the grade of the receiving pervious area is greater than 1% and less than 5%, or can be applied to individual terraces with slopes of 1-5%. The slope of the receiving areas must be graded away from any building foundations. Turf reinforcement may include biodegradable erosion control matting or other appropriate reinforcing materials that are confirmed by the designer to be non-erosive for the specific characteristics and flow rates anticipated at each individual application, and acceptable to the plan approving authority.

Soils and Underdrains. Impervious Surface Disconnection can be used on any post-construction HSG. However, for Simple Disconnection, the permeability of the receiving pervious area is an important factor in the runoff reduction performance. Therefore, HSGs A & B receive a higher annual runoff reduction credit than HSG C & D soils. The performance of disconnection in HSG C & D soils can be improved by providing Soil Amendments (e.g., compost-amended filter path) or a Compensatory Practice (e.g., infiltration, bioretention, or cisterns).

The performance credit is designated by soil type; however, the premise of the credit is the minimum theoretical permeability or infiltration rate of 0.5 in./hr. for HSG A & B soils. The designer should verify the soil type as well as the erodibility of the soils by conducting a geotechnical investigation.

Use Caution When Infiltrating Water in Fill Sections

Soil slips can result from infiltrating water in areas of fill material, especially if the interface between the fill material and the native soil is shallow and on a steep grade (as compared to the gentle topography of the finished grade). Geotechnical investigations are required if any design that infiltrates water is proposed in a fill section.

Contributing Drainage Area. For rooftop impervious areas, the maximum impervious area treated cannot exceed 1,000 sq. ft. per disconnection. For non-rooftop impervious areas, the longest contributing impervious area flow path cannot exceed 75 feet.

Hotspot Land Uses. Simple Disconnection should not be used in areas of potential or confirmed hotspots. However, disconnection can still be used to treat "non-hotspot" parts of the site; for instance, rooftop runoff and small parking areas can be disconnected to a pervious area while vehicular maintenance areas or other stormwater hotspot sources would be treated by a more appropriate hotspot practice.

For a list of potential stormwater hotspots, please consult Chapter 5 of the Manual.

Floodplains. Stream buffers and other pervious areas typically associated with floodplains should not be used for disconnection credit without prior approval from the local plan approving authority (see **Specification 4.1** Better Site Design Practices).

Setbacks. If the grade of the receiving area is less than 1%, downspouts must be extended 5 ft. away from building. Note that the downspout extension of 5 feet is intended for simple foundations. The use of a dry well or french drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's water-proofing system (foundation drains, etc.), or avoided altogether.

Proximity to Utilities. Interference with underground utilities should be avoided whenever possible, particularly water and sewer lines. However, the limited contributing drainage area and the continuous grade of disconnection areas is such that the presence of underground utilities should not preclude the practice from being used. Since conflicts with water and sewer laterals (e.g., house connections) in residential settings may be unavoidable, the construction sequence must be considered to ensure the stabilization of the disconnection flow path occurs after the installation of utilities that intersect the flow path.

Community Factors. Simple Disconnection is a safe and easy way to reduce the effect of impervious cover by utilizing the surrounding landscape. Since this can be a very subtle practice, property owners must be specifically advised as to the presence of the practice. Disconnection to Compensatory Practices (e.g. disconnection to cisterns or rain gardens) are more visible, and have the added community benefits of aesthetics and educational opportunity.

Underground Injection Permits. Simple Disconnection is generally not subject to permits under the Underground Injection Control (UIC) Program (U.S. EPA, 2008). However, certain Compensatory Practices, especially infiltration, may require consideration when in close proximity to sensitive groundwater areas (e.g., aquifers overlain with thin, porous soils), and/or designs that are deeper than their widest surface dimension.

4.2.2. Impervious Surface Disconnection (ID)
ID-4. Design Criteria

The following design criteria apply to Simple Disconnection and Disconnection with Compensatory Practices:

ID-4.1. Simple Disconnection
Simple Disconnection should be designed in accordance with the following criteria:

Table ID-4. Simple Disconnection

Design Factor	Design Criteria
Impervious Area Treated	• 1,000 sq. ft. per rooftop disconnection. • Non-rooftop impervious areas: longest contributing impervious area flow path ≤ 75 ft.
Sizing/Geometry	• Pervious disconnection area width: ≥ 15 ft. and ≤ 25 ft. • Pervious disconnection area length: 40 ft.
Grade	• ≤ 2% • ≤ 5% with turf reinforcing • receiving areas must be graded away from any building foundations
Inflow	• Sheet flow with level spreader for the entire width of the pervious area

Design Factor	Design Criteria
Pretreatment	• Generally not required (other than level spreader) for Simple Disconnection
Minimum Soil Infiltration Rate	• 0.5 inches/hour for Simple Disconnection (or use Compensatory Practice)
Building Setbacks	• 5 ft. away from building if the grade of the receiving area is less than 1%
Underdrains	• Generally not required for Simple Disconnection
Impermeable Liner	• Generally not required for Simple Disconnection

Level Spreader: A level spreader must be used to disperse or "spread" concentrated flow thinly over the vegetated pervious area to promote greater runoff infiltration and minimize erosion. A level spreader consists of a permanent linear structure constructed at a 0% grade that transects the slope. The influent concentrated runoff must be spread over the entire width of the pervious area. Detailed information on the design and function of level spreaders can be found in Hathaway and Hunt (2006) and Van Der Wiele (2007).

- The minimum required width of the level spreader should be equal to the width of the disconnection flow path.
- A pea gravel or river stone diaphragm, concrete, timber, or other accepted flow spreading device should be installed at the downspout outlet to distribute flows evenly across the filter path.

More details about level spreader design can be obtained from **Specification 4.2.1. Sheet Flow to Vegetated Filter Strips and Conservation Areas.**

Conveyance. Simple Disconnection should be designed to safely convey design and large storm events over the receiving area without causing erosion. Since the rooftop drainage systems (roof leaders) typically limit the flow, there are generally no detailed conveyance criteria related to a design storm or peak flow rate.

The strip should have adequate "freeboard" so that flow remains within the strip and is not diverted away from the strip. This means that the strip should be lower than the surrounding land area in order to keep flow in the filter path. Similarly, the flow area of the filter strip should be level to discourage concentrating the flow down the middle of the filter path.

Landscaping. Landscaping of pervious areas for Simple Disconnection consists of designating an appropriate grass species for the site conditions. All receiving disconnection areas must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. Several types of grasses appropriate for disconnection practices are listed in **Specification 4.2.5. Grass Swales** and WVDEP (2006).

ID-4.2 Simple Disconnection to a Soil Compost-Amended Filter Path

For detailed information on the design, function, and specifications for the incorporation of Soil Amendments, designers should consult **Appendix D**.

The pervious area for Simple Disconnection to a soil compost-amended filter path should meet the design criteria in **Table ID-4,** as well as the following:

- The amended filter path should be at least 10 feet in width and 20 feet in length within the larger disconnection pervious area.
- A simple level spreading device (e.g., stone apron, gravel diaphragm) should be installed at the downspout outlet to distribute flows evenly across the filter path.
- Use 2 to 4 inches of approved compost material and till to a depth of 6 to 10 inches within the filter path.

ID-4.3 Disconnection with Compensatory Practice: Infiltration

Depending on soil properties, rooftop runoff may be infiltrated into a shallow dry well or french drain. The design for this Compensatory Practice should meet the requirements of Infiltration practices, as described in **Specification 4.2.6**. Infiltration and summarized in **Table ID-5** below. Note that the building setback of 5 feet is intended for simple foundations. The use of a dry well or french drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's water-proofing system (foundation drains, etc.), or avoided altogether.

Table ID-5. Disconnection with Compensatory Practice: Infiltration

Design Factor	Infiltration Design
Roof Area Treated	250 to 2,500 sq. ft.
Typical Practices	Dry well and french drain
Recommended Maximum Depth	3 ft.
Sizing	See **Specification 4.2.6: Infiltration**
Minimum Soil Infiltration Rate	Field verified ≥ 0.5 in./hr.
Observation Well	No
Pretreatment	External (leaf screens, grass strip, etc.)
UIC Permit	Possible[1]

Design Factor	Infiltration Design
Head Required	Nominal, 1 to 3 ft.
Required Soil Test	One per practice
Building Setbacks	5 ft. down-gradient[2], 25 ft. up-gradient

[1] *Infiltration practice must be wider than it is deep to avoid an underground injection control permit. See* **Specification 4.2.6** *Infiltration for more information.*
[2] *Note that the building setback of 5 ft. is intended for simple foundations. The use of a dry well or french drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's water-proofing system (foundation drains, etc.), or avoided altogether.*

In general, micro-infiltration areas will require a surface area up to 3% of the contributing roof area. An on-site soil test is needed to determine if soils are suitable for infiltration. It is recommended that the micro-infiltration facility be located in an expanded right-of-way or stormwater easement so that it can be accessed for maintenance.

Conveyance. Disconnection to Infiltration should include provisions to bypass flows around the Infiltration practice when the rain event exceeds the design volume. The adjacent pervious areas should be designed to safely convey design and large storm events away from the practice and to a receiving area without causing erosion. Since the rooftop drainage systems (roof leaders) typically limit the flow, there are generally no detailed conveyance criteria related to a design storm or peak flow rate.

Landscaping. Landscaping of Infiltration areas can include a layer of top soil and turf. Refer to **Specification 4.2.6. Infiltration** for the design elements of turf cover over top of an Infiltration practice.

ID-4.4 Disconnection with Compensatory Practice: Bioretention (Residential Rain Gardens and Urban Bioretention)

For some residential applications, front, side, and/or rear yard Rain Garden may be an attractive option used to filter roof runoff (**Figures ID-2** through **ID-5 and ID-7**). The term Residential Rain Garden generally refers to a less rigorous design specification since the contributing drainage area is limited. Refer to **Specification 4.2.3 Appendix C: Residential Rain Gardens**. Where more than one structure drains to a shared Rain Garden, or the drainage area exceeds the maximum noted below, the design criteria for Bioretention (**Specification 4.2.3**) would apply.

Urban Bioretention in stormwater planters are also a useful option to disconnect and treat rooftop runoff, particularly in ultra-urban areas. The designs for both of these options should meet the requirements described in **Specification 4.2.3 Bioretention** and the criteria summarized in **Table ID-6** below.

Figure ID-7. A backyard rain garden that treats rooftop runoff

Table ID-6. Design Criteria for Disconnection to Residential Rain Garden

Design Factor	Residential Rain Garden Design
Impervious Area Treated[1]	2,500 sq. ft.
Type of Inflow	Sheet flow; Concentrated flow with level spreader or energy dissipater
Minimum Soil Infiltration Rate	0.5 in./hr. (or use underdrain)
Observation Well/Cleanout Pipes	No
Pretreatment	Energy dissipater, forebay, grass filter
Underdrain	Optional per soils[1]
Impermeable Liner	For hotspot or karst designs, or adjacent to foundations.
Gravel Layer	12 in.

Design Factor	Residential Rain Garden Design
Minimum Filter Media Depth	18 in.
Media Source	Can be mixed on-site
Head Required	Nominal, 1 to 3 ft.
Sizing	See **Specification 4.2.3: Bioretention**
Required Soil Borings	One, only when an underdrain is not used
Building Setbacks	5 ft. down-gradient, 25 ft. up-gradient (or use an impermeable liner for planters)

[1]*Refer* ***Specification 4.2.3 Bioretention***

Conveyance. Disconnection to Rain Gardens should include provisions to bypass flows around the practice when the rain event exceeds the design volume. The adjacent pervious areas should be designed to safely convey design and large storm events away from the practice and to a receiving area without causing erosion. Since the rooftop drainage systems (roof leaders) typically limit the flow, there are generally no detailed conveyance criteria related to a design storm or peak flow rate. Refer to **Specification 4.2.3 Bioretention Appendix C: Residential Rain Gardens**.

Landscaping: Residential Rain Gardens should be landscaped in accordance with Section BR-4.17 in **Specification 4.2.3, Bioretention**.

ID-4.5 Storage and Reuse with a Cistern or Rain Tank

This form of disconnection must conform to the design requirements outlined in **Specification 4.2.8. Rainwater Harvesting**. The runoff reduction rates for rain tanks and cisterns depends on their storage capacity and ability to draw down water in between storms for reuse as potable water, grey-water or irrigation use. The actual runoff reduction rate for a particular design can be ascertained using the design annual rainfall depth and the intended use of the water: landscaping irrigation, internal non-potable uses, etc. Refer to **Specification 4.2.8. Rainwater Harvesting**.

Pretreatment. Pretreatment for Rainwater Harvesting systems is critical to keeping the internal components clear of debris. External leaf screens, a first flush diverter, and other options should be considered in the early stages of design. Refer to **Specification 4.2.8. Rainwater Harvesting**.

Conveyance and Overflow. The design of Rainwater Harvesting systems should be in accordance with **Specification 4.2.8. Rainwater Harvesting**. All devices should have a suitable overflow area to route extreme flows into the next treatment practice or the stormwater conveyance system.

4.2.2. Impervious Surface Disconnection (ID)

ID-5. Materials Specifications

Materials Specifications for Simple Disconnection and Disconnection with Compensatory Practices can be found in the specifications for the individual practices. Refer to the following:

Specification 4.2.1: Sheet Flow to Vegetated Filter Strips and Conservation Areas (for Level Spreader);
Specification 4.2.3: Bioretention
Specification 4.2.6: Infiltration
Specification 4.2.8: Rainwater Harvesting
Appendix D: Soil Amendments

4.2.2. Impervious Surface Disconnection (ID)

ID-6. Design Adaptations

ID-6.1. Karst Terrain

Impervious Surface Disconnection is strongly recommended for most residential lots greater than 6,000 square feet, particularly if it can be combined with a secondary small scale (compensatory) practice to increase runoff reduction. The discharge point from the disconnection should extend at least 15 feet from any building foundations. Impervious Surface Disconnection is also recommended for commercial sites that are not likely to be stormwater hotspots.

ID-6.2. Steep Slopes

Simple Disconnection is generally not appropriate on steep slopes. However, terracing can establish pockets or relatively flat area for either Simple Disconnection or Disconnection with Compensatory Practices. Refer to Design Adaptations in the individual practice design specifications for specific guidance.

ID-6.3. Stormwater Retrofitting

Simple Disconnection is an on-site retrofit technique with the goal of systematically retrofitting as many rooftop and/or on-lot residential impervious surfaces as possible within a given watershed. Some of the chief considerations for retrofitting are available space, soil permeability, and soil compaction.

For more information on retrofitting, see the Center for Watershed Protection's manual, Urban Stormwater Retrofit Practices (Schueler et al., 2007).

ID-7. Construction & Installation

Residential Impervious Surface Disconnection will often be identified on the construction drawings before the designer knows the dimensions and exact location of the dwelling unit. Therefore, designers should identify reasonable areas on each lot as being protected for future use until such time as a final house location plat is developed and the pervious areas of Compensatory Practices can be sited.

In the meantime, care should be taken during site construction to protect the disconnection pervious areas in the vicinity of the proposed house and driveway location from compaction. To help prevent soil compaction, heavy vehicular and foot traffic should be kept out of the receiving pervious area both during and after construction. This can be accomplished by clearly delineating the receiving pervious areas on all development plans and protecting them with temporary fencing prior to the start of land disturbing activities. If compaction occurs, the soils should be amended or aerated post-construction to increase permeability.

ID-7.1. Construction Sequence for Simple Disconnection

For Simple Disconnection, the receiving pervious area can be within the limits of disturbance during construction. The following procedures should be followed during construction:

- Before site work begins, the receiving pervious disconnection area boundaries should be clearly marked.
- Construction traffic in the disconnection area should be limited to avoid compaction. The material stockpile area shall not be located in the disconnection area.
- Construction runoff should be directed away from the proposed disconnection area, using perimeter silt fence, or, preferably, a diversion dike.
- If existing topsoil is stripped during grading, it shall be stockpiled for later use.
- The disconnection area may require light grading to achieve desired elevations and slopes. This should be done with tracked vehicles to prevent compaction.
- Topsoil and/or compost amendments should be incorporated evenly across the disconnection area, stabilized with seed, and protected by biodegradable erosion control matting or blankets.
- Stormwater should not be diverted into any compost amended areas until the turf cover is dense and well established.

ID-7.2 Construction Inspection

Construction inspection is critical to ensure compliance with design standards. Inspectors should evaluate the performance of the disconnection after the first big storm to look for evidence of gullies, outflanking, undercutting or sparse vegetative cover. Spot repairs should be made, as needed.

An example construction phase inspection checklist is available in **Appendix A** of this Manual.

4.2.2. Impervious Surface Disconnection (ID)

ID-8. Maintenance Criteria

Maintenance of disconnected downspouts usually involves regular lawn or landscaping maintenance in the filter path from the roof to the street. In some cases, runoff from a Simple Disconnection may be directed to a more natural, undisturbed setting (i.e., where lot grading and clearing is "fingerprinted" and the proposed filter path is protected).

Maintenance agreements must be executed between the owner and the local authority. The agreements will specify the property owner's primary maintenance responsibilities and authorize local agency staff to access the property for inspection or corrective action in the event that proper maintenance is not performed. The agreements must ensure that downspouts remain disconnected, treatment units are maintained and filtering/infiltrating areas are not converted or disturbed.

When the disconnection occurs on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to modified maintenance agreements as described above.

Rooftop disconnection areas and supplementary treatment devices must be covered by a drainage easement to allow inspection and maintenance.

Example maintenance inspection checklists for disconnection areas can be found in Appendix A of this Manual.

REFERENCES

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4.2.3 Bioretention

BR-1. Introduction

Bioretention is a versatile stormwater practice that filters runoff through plants, an engineered soil mix, and often an underdrain.

Bioretention can be used to:

- Manage the first one inch of rainfall on-site using an Infiltration Design with no underdrain (See **Table BR-1**, Level 2 design)
- Manage the first one inch of rainfall on-site using an Extended Filtration Design with an underdrain (**See Table BR-1**, Level 2 design)
- Partially manage the first one inch of rainfall on-site using a Basic Design with an underdrain (See **Table BR-1**, Level 1 design)
- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs; See **Table BR-2**).
- Meet partial or full storage requirements for local stormwater detention standards
- Retrofit existing developed areas, especially highly impervious areas

Bioretention can be blended into the landscape design for many sites. As examples, the photo on the left shows a Bioretention cell in the bus loop of a high school. The photo on the right illustrates a linear and sloped Bioretention (called a "Water Quality Swale") along a residential street, using stone check dams to break the swale into individual cells.

For the purposes of this section, "Bioretention" refers to flat-bottomed cells of various shapes and configurations. Other variations of the basic Bioretention concept are included in the supplements to this section:

- Water Quality Swale (**Supplement 4.2.3.A**) -- linear and narrower applications, often with a longitudinal slope (see photo on right above).
- Urban Bioretention (**Supplement 4.2.3.B**) – adaptations for highly impervious settings; includes street Bioretention, engineered tree pits, and stormwater planters.
- Residential Rain Garden (**Supplement 4.2.3.C**) – simplified version designed for residential yards and small-scale applications.

Figure BR-1 further illustrates typical Bioretention applications. **Figure BR-2** is a schematic of a typical Bioretention area. **Tables BR-1 and BR-2** describe two levels of Bioretention design and associated volume reduction and pollutant removal performance rates. **Table BR-3** is a design checklist to help guide the design process for Bioretention practices.

BR-1.1. Planning This Practice

BEFORE

AFTER

Figure BR-1. Typical Applications for Bioretention & Water Quality Swales

Edge of Parking Lot

(Computer simulation by Center for Watershed Protection)

Parking Lot Island

(Computer simulation by Center for Watershed Protection)

BEFORE

AFTER

To Treat Rooftop Runoff

(Computer simulation by Center for Watershed Protection)

In Bus Loops & Grassy Areas Adjacent to Parking Lots and Travelways

In the Street Right-of-Way (Can be Associated with Traffic Calming (Urban Bioretention))

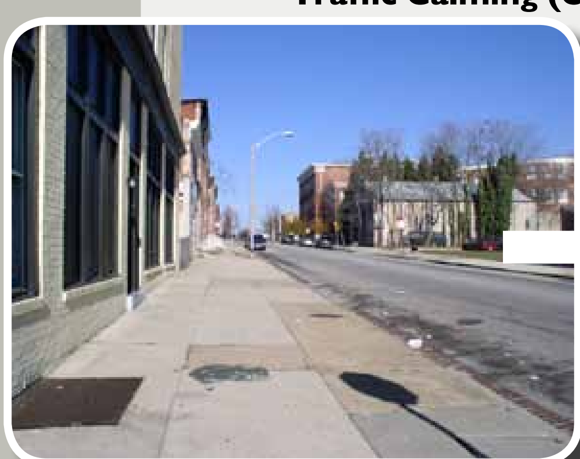

Figure BR-2. Schematic Profile for Typical Bioretention

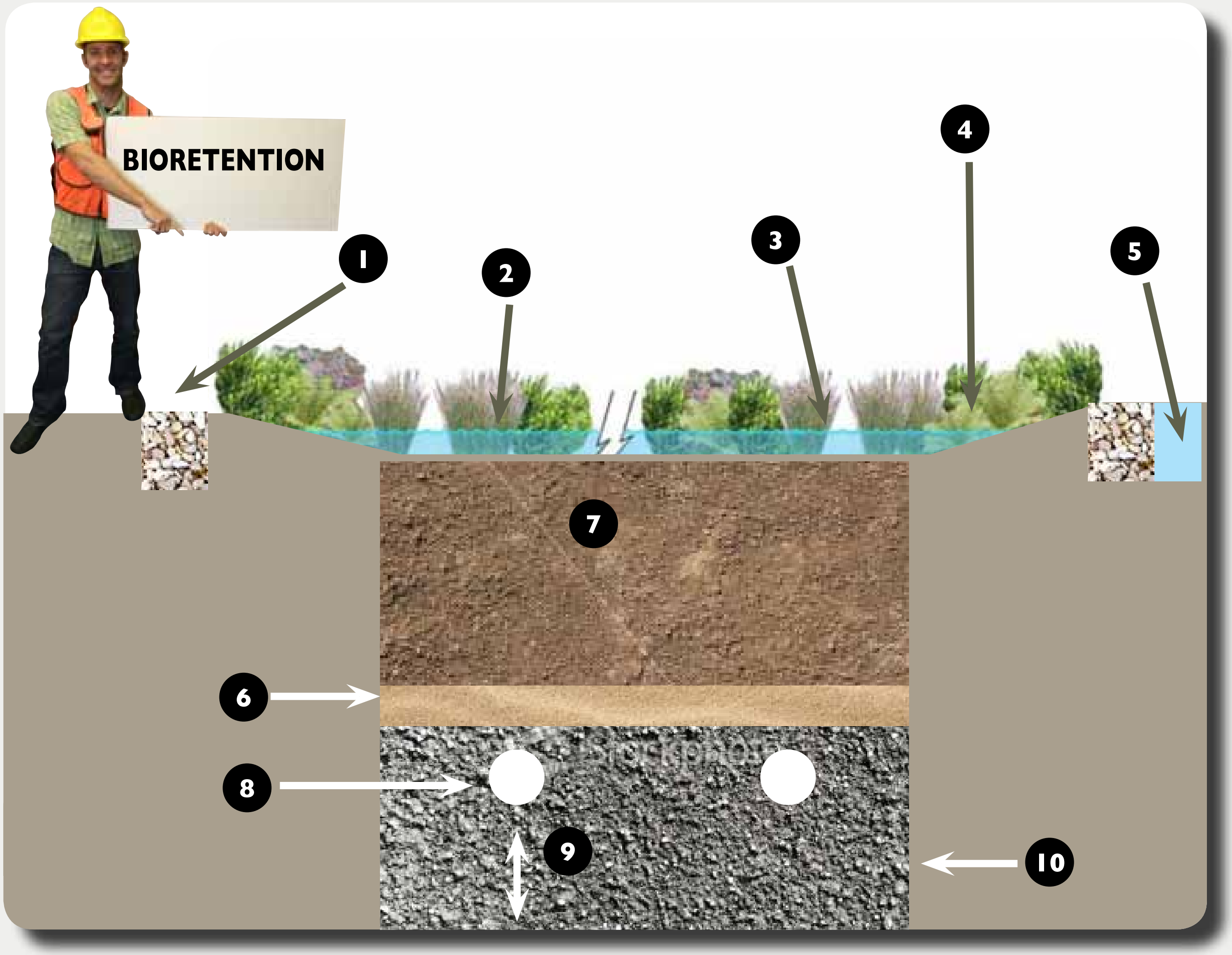

Figure 2. Schematic Profile for Typical Bioretention (Source for base graphic: San Mateo County Sustainable Green Streets and Parking Lots Guidebook (San Mateo County, CA, 2009).

1. Pretreatment (typical) - Section BR-4.3
2. Surface Cover & Plantings - Sections BR-4.9 & BR-4.17
3. Ponding Depth = 6" – 18" - Section BR-4.6
4. Side Slopes = 3:1 max (recommended) - Section BR-4.7
5. Overflow Structure for Larger Flows - Section BR-4.4
6. Choker Layer = 1" choker stone for every 1' of soil media - Section BR-4.12
7. Soil Media = 18" min. - Section BR-4.8 & Table BR-1
8. 4" – 6" Underdrain Pipes - Section BR-4.10
9. Optional Infiltration Sump Below Underdrain Pipes - Section BR-4.11
10. Underdrain Stone Layer - Section BR-4.10

BR-1.2. Bioretention Design Options & Performance

Table BR-1 describes the Level 1 and Level 2 design options for Bioretention and the practice performance in terms of reducing the volume associated with one inch of rainfall on the site. **Table BR-2** summarizes the pollutant removal performance values for Level 1 and Level 2 designs. This is for the purpose of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans.

Table BR-1. Bioretention Design Levels: Descriptions & Performance

Design Level	Description	Applications	Performance1
Level 1	Basic Design (**Figure BR-3**) • Underdrain • At least 1.5 ft. of soil media depth, but less than 2.0 ft. • No infiltration sump below underdrain pipe(s)	Sites with vertical constraints such as high bedrock or water table or confirmed karst, stormwater hotspot, or other applications that require an impermeable liner.	60% volume reduction for the Design Volume of the practice[2]
Level 2	Infiltration Design (**Figure BR-4**) • No underdrain • Water infiltrates into the underlying soil within 48 hours. OR Extended Filtration Design (**Figures BR-5, 6, 7**) • Underdrain • At least 2.0 ft. of soil media depth, OR • At least 1.5 ft. of soil media depth with stone sump below underdrain designed to drain Design Volume within 48 hours on suitable soils (e.g., limited on fill) or upturned elbow underdrain design	Generally most sites that have good to marginal infiltration rates -- HSG A, B, and C and do not require an impermeable liner. Use the Infiltration Design for tested infiltration rates > 0.5 in. per hr., and the Extended Filtration Design for other sites.	100% volume reduction for the Design Volume of the practice[2]

[1] *Performance achieved toward reducing one inch of rainfall*

[2] *Design Volume includes storage on the surface, within the soil media, and in the infiltration sump. The Design Volume can be 100% of that needed to meet the one inch performance standard for the contributing drainage area ("Target Treatment Volume") or some proportion of it when used in conjunction with other practices. See* **Section BR-4.1** *for sizing details.*

Table BR-2. Total Pollutant Load Reduction Performance Values for Level 1 and 2 Design

Design Level	Total Suspended Solids (TSS)[1]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)[1]
Level 1	TSS = 70%	TP = 55% TN = 64%
Level 2	TSS = 95%	TP = 90% TN = 92%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008).

BR-1.3. Bioretention Design Checklist

Table BR-3. Bioretention Design Checklist

CHECKLIST

This checklist will help the designer step through the necessary design steps for bioretention.

- ☐ This checklist will help the designer with the necessary design steps for Bioretention.
- ☐ Check feasibility for site – Section BR-3
- ☐ Determine whether an Infiltration or Extended Filtration Design is best for the site. Use Level 2 design unless site constraints necessitate the Level 1 Basic Design – **Table BR-1**
- ☐ Complete Design Compliance Spreadsheet to plan and confirm required Bioretention sizing, additional practices needed, and overall site compliance – Design Compliance Spreadsheet & Chapter 3 of Manual
- ☐ Check Bioretention sizing guidance and make sure there is an adequate footprint (often split into multiple areas) on the site for Bioretention – Sections BR-4.1 & BR-4.2
- ☐ Check design adaptations appropriate to the site – Section BR-6
- ☐ Design Bioretention in accordance with design criteria and typical details – Sections BR-2 & BR-4
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence notes

BR-2. Typical Details

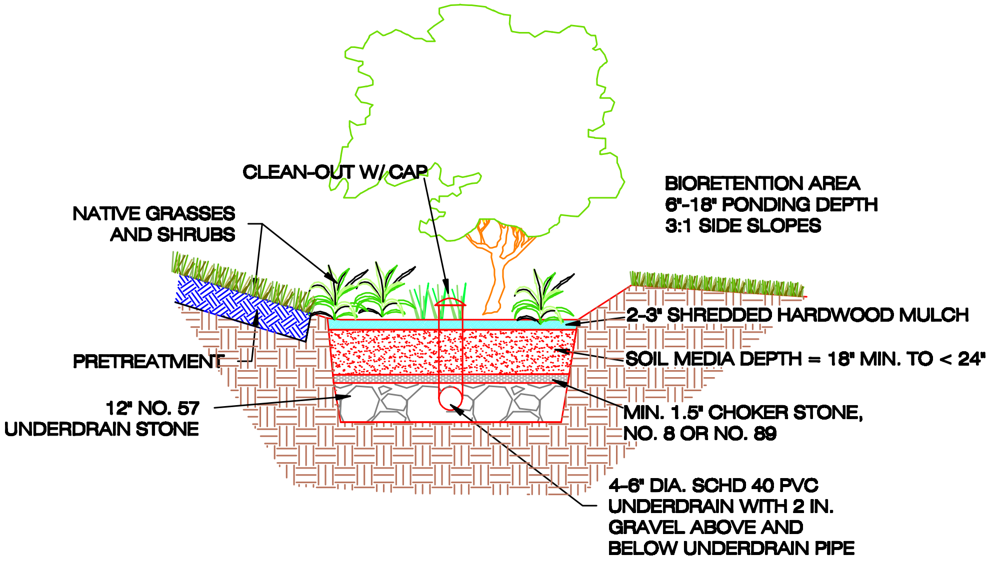

Figure BR-3. Typical Detail for Level 1 Design

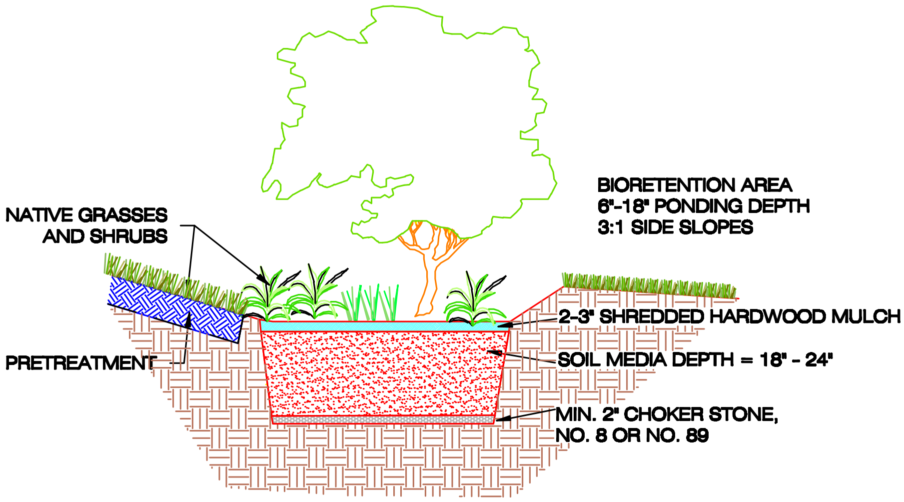

Figure BR-4. Typical Detail for Level 2 Infiltration Design (No Underdrain)

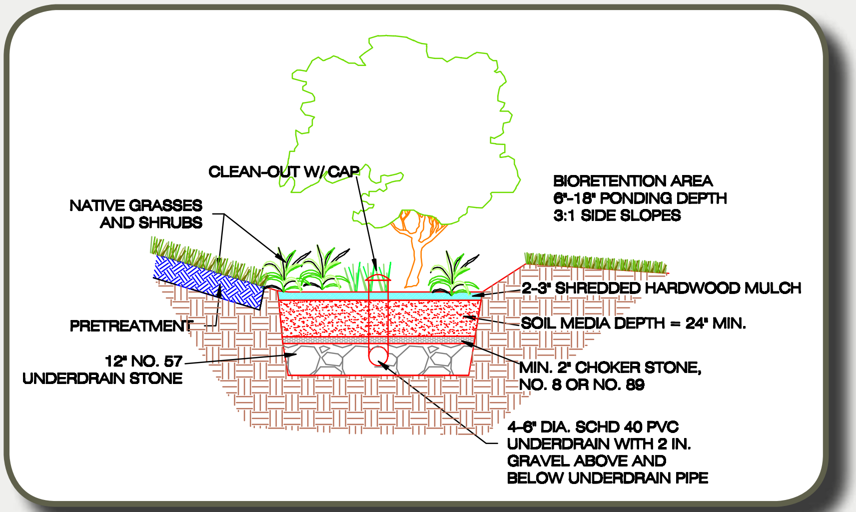

Figure BR-5. Typical Detail for Level 2 Extended Filtration Design, Option 1 (Min. 2' of Soil Media)

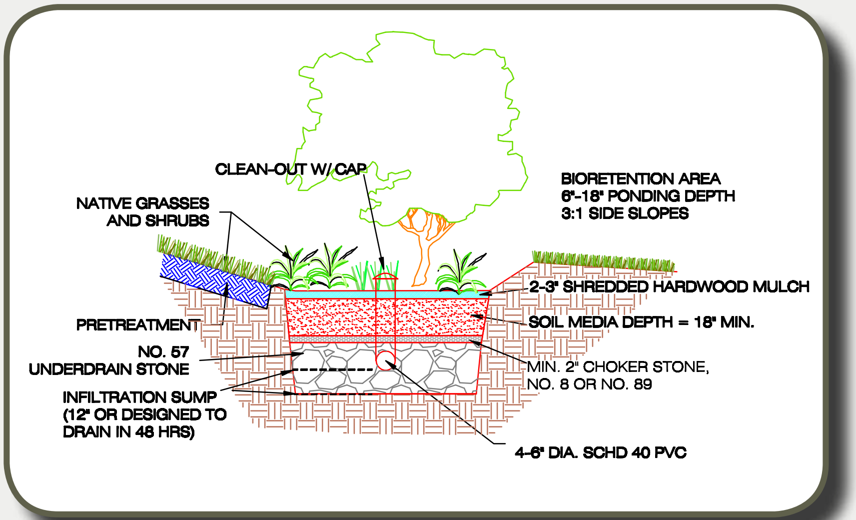

Figure BR-6. Typical Detail for Level 2 Extended Filtration Design, Option 2 (Min. 1.5' of Soil Media With Stone Sump)

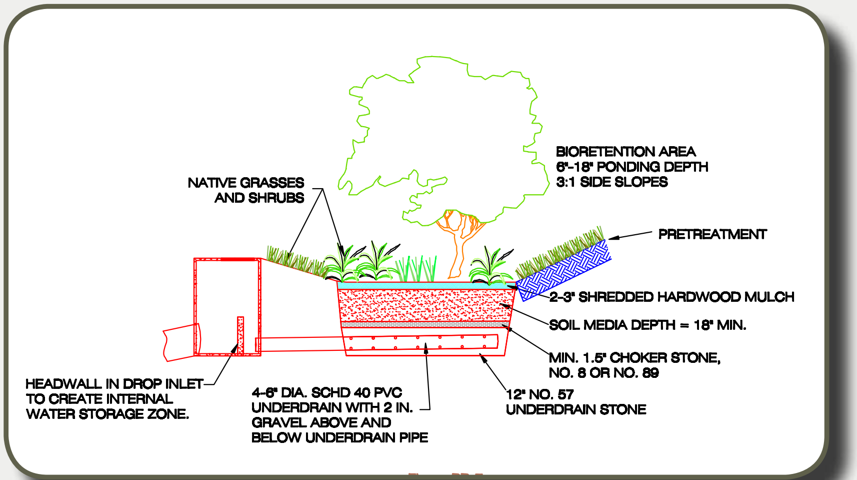

Figure BR-7. Typical Detail for Level 2 Extended Filtration Design, Option 3 (Min. 1.5' of Soil Media With Upturned Elbow Underdrain Design)

BR-3. Feasibility Criteria and Design Considerations

Bioretention can be applied in most soils or topography, since runoff simply percolates through an engineered soil bed and is infiltrated or returned to the stormwater system via an underdrain. Key constraints with Bioretention include the following:

Available Space. Planners and designers can assess the feasibility of using Bioretention facilities based on a simple relationship between the contributing drainage area (CDA) and the corresponding required surface area. The Bioretention surface area will usually be approximately 3% to 6% of the CDA, depending on the imperviousness of the CDA and the desired Bioretention ponding depth.

Site Topography. Bioretention can be used for sites with a variety of topographic conditions, but is best applied when the grade of the area immediately adjacent to the bioretention practice (within approximately 15 to 20 feet) is greater than 1% and less than 5%. For sites with steep grades, Bioretention should be split into multiple cells with adequate conveyance between the cells to take advantage of relatively flat and/or areas in cut sections (rather than fill).

Available Hydraulic Head. Bioretention is fundamentally constrained by the invert elevation of the existing conveyance system to which the practice discharges (i.e., the bottom elevation needed to tie the underdrain from the Bioretention area into the storm drain system). In general, 4 to 5 feet of elevation above this invert is needed to accommodate the required ponding and filter media depths. For infiltration designs, the available head is less important.

Water Table. Bioretention should always be separated from the water table to ensure that groundwater does not intersect the filter bed. Mixing can lead to possible groundwater contamination or failure of the Bioretention facility. A separation distance of 2 feet is required between the bottom of the excavated Bioretention area and the seasonally high ground water table.

Soils and Underdrains. Soil conditions do not typically constrain the use of Bioretention, although they do determine whether an underdrain is needed. Underdrains are needed if the measured permeability of the underlying soils is less than 0.5 inches per hour. When designing Bioretention practices without underdrains and with drainage areas greater than 0.5 acre, designers should verify soil permeability by using the on-site soil investigation methods provided in Appendix B of the Manual.

Use of Bioretention on Fill Section

In areas of significant fill, soil slips can result from infiltrating water, including use of an infiltration sump. It is preferable to use this type of design in cut sections. Geotechnical investigations are required if any design that infiltrates water will be used in a fill section. Impermeable liners and underdrains (without a sump) may be necessary, based on the outcome of the investigation (**see Section BR-4.15**).

Contributing Drainage Area. Bioretention cells work best with smaller CDAs, where it is easier to achieve flow distribution over the filter bed. Typical drainage area size for traditional Bioretention areas can range from 0.1 to 2.5 acres and consist of up to 100% impervious cover. Drainage areas to smaller Bioretention practices (Urban Bioretention, Residential Rain Gardens) typically range from 0.5 acre to 1.0.

Hotspot Land Uses. An impermeable bottom liner and an underdrain system must be employed when a Bioretention area will receive untreated stormwater hotspot runoff (e.g., vehicle maintenance facilities). However, Bioretention can still be used to treat "non-hotspot" parts of the site; for instance, rooftop runoff can go to Bioretention while vehicular maintenance areas would be treated by a more appropriate hotspot practice.

For a list of potential stormwater hotspots, please consult **Chapter 5 of the Manual.**

Floodplains. Bioretention areas should be constructed outside the limits of the 100-year floodplain, unless a waiver is obtained from the local authority.

No Irrigation or Baseflow. The planned Bioretention area should not receive baseflow, irrigation water, chlorinated wash-water or other such non-stormwater flows.

Setbacks. To avoid the risk of seepage, do not allow Bioretention areas to be hydraulically connected to structure foundations. Setbacks to structures vary based on the size of the Bioretention design:

- 0 to 0.5 acre CDA = 10 feet if down-gradient from building; 50 feet if up-gradient.
- 0.5 to 2.5 acre CDA = 25 feet if down-gradient from building; 100 feet if up-gradient.

If an impermeable liner and an underdrain are used, no building setbacks are needed for Urban Bioretention (e.g., stormwater planters) and Residential Rain Garden designs.

At a minimum, Bioretention basins should be located a horizontal distance of 100 feet from any water supply well (50 feet if the Bioretention practice is lined).

Proximity to Utilities. Interference with underground utilities should be avoided whenever possible, particularly water and sewer lines. Approval from the applicable utility company or agency is required if utility lines will run below or through the Bioretention area. Conflicts with water and sewer laterals (e.g., house connections) may be unavoidable, and the construction sequence must be altered, as necessary, to avoid impacts to existing service.

Additionally, designers should ensure that future tree canopy growth in the Bioretention area will not interfere with existing overhead utility lines.

Community Factors. Bioretention can be designed as safe and aesthetically pleasing practices. If the practice will be used in areas with heavy foot traffic, highly visible areas, residential or commercial areas, and/or areas where safety is a concern, the ponding depth should be limited to 6 to 12 inches.

Underground Injection Permits. Bioretention areas are generally not considered to be Class V wells subject to permits under the Underground Injection Control (UIC) Program (U.S. EPA, 2008). However, in certain cases the designer should confer with West Virginia Department of Environmental Protection (WVDEP) about the possible applicability of a UIC permit. These cases would include infiltration designs (or designs that include an infiltration sump) in close proximity to sensitive groundwater areas (e.g., aquifers overlain with thin, porous soils), designs with a subsurface fluid distribution system (e.g., underdrains that do not discharge to the surface or the storm drain system), and/or designs that are deeper than their widest surface dimension.

BR-4. Design Criteria

BR-4.1. Bioretention Sizing for Water Quality & Volume Reduction

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a best management practice (BMP) plan:

Target Treatment Volume (Tv) = Volume associated with managing one inch of rainfall based on the size and land cover of the CDA, as determined by the Design Compliance Spreadsheet. Any given BMP may treat the full Tv or only part of it if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on storage within different layers as prescribed in the BMP specification. The Dv can equal the Target Treatment Volume (Tv) if there is only one BMP in the CDA. Where multiple BMPs are used as part of a treatment train, the Dv may only be part of the overall Tv for the drainage area, with the sum of each BMP's Dv equaling or exceeding the Tv.

See Chapter 3 for more information on the runoff reduction design methodology.

For the purposes of this sizing section, the sizing relates to the Dv of the practice being designed.

Bioretention sizing includes four basic steps:

1. **Surface Ponding:** Provide adequate surface ponding to capture enough of the Design Volume and allow it to begin filtering through the soil media;
2. **Soil Media & Underdrain Gravel Storage:** Provide adequate surface area and depth of the soil media and gravel layer. The soil media serves to retain and filter the Design Volume, while the gravel layer protects the underdrain (if provided) or the infiltration capacity of the underlying soils (if available);
3. **Verify Total Design Volume:** Verify that the combination of surface ponding, soil media, and gravel storage is adequate to manage the Design Volume
4. **Other Design Features:** Provide adequate pretreatment, flow geometry, and other design features to ensure the long term performance of the system.

The selection of Level 1 or Level 2 design will determine the target sizing as defined in these basic steps. The designer is encouraged to review the feasibility criteria and design considerations in Section BR-3 in order to optimize the performance of the system with regard to possible site constraints.

Step 1: Surface Ponding:

The required surface ponding volume of Bioretention practices is a function of the surface ponding depth and the anticipated Design Volume. The following surface storage requirements apply:

- For ponding depths of less than 1 foot, surface storage should account for at least 50% of the required total Design Volume within the practice.
- For ponding depths of 1 foot or more (18 inches maximum), surface storage should account for at least 70% of the total Design Volume.

In either case, the ponding volume surface area can be larger if additional storage is desired.

These minimum surface storage requirements are based on the need to capture the one-inch runoff volume from a full range of expected storm intensities. Rainfall distribution in the mid-Atlantic includes both short intense storms, as well as long, steady, low-intensity rain events. During high intensity storm events, the Bioretention practice may fill up faster than the collected stormwater is able to filter through the soil media. In addition, the hydraulic conductivity of the surface layer of mulch and the soil media will vary over the maintenance life-cycle of the practice. Therefore, an adequate ponding volume is necessary to allow the runoff to begin to filter into the soil media before the runoff bypasses or overflows the surface storage.

The local authority may modify or reduce the 50% or 70% surface storage requirement in circumstances where it makes a Bioretention application impractical. In such cases, the following design adaptations are recommended:

- The drainage area is no larger than 0.75 acre.
- Additional plantings/landscaping is added to any additional ponding area.

Step 2: Soil Media and Underdrain Gravel Storage:

The soil media and gravel layer provide the required remaining storage volume within the void spaces to manage the Design Volume. The design of these components therefore includes a surface area and a depth. The depth can vary; however, the selection of a Level 1 or Level 2 design will require that a minimum depth of soil and/or gravel be provided in order to achieve the corresponding volume reduction credit. Refer to **Table BR-1** for Level 1 and Level 2 standards.

The surface area of these components can similarly vary. However, there is a design relationship between the minimum surface area of the soil media and the surface area of the ponding volume as described in Step 1 above. The ponding surface area can be larger than the surface area of the soil media according to the following guidelines:

- If the ponding depth is less than 1 foot, the ponding surface area can exceed the soil media surface area by up to 50%.
- If the ponding depth is 1 foot or more (up to 1.5 feet), the ponding surface area can exceed the soil media surface area by up to 25%.

These guidelines are to ensure that the soil layer provides adequate hydraulic loading capacity for the design ponding volume. **Table BR-4** provides a summary of the surface area criteria and **Figure BR-8** illustrates the additional ponding area in graphical format.

The surface ponding volume determination should take into account surface side slopes and can be computed using **Equation BR-1**:

Equation BR-1. Bioretention Surface Ponding Volume

$$\textit{Surface Ponding Volume} = (SA_{avg\text{-}ponding} \times d_{ponding})$$

Where:

Surface Ponding Volume	=	volume of storage provided above the soil media layer (ft^3)
$SA_{avg\text{-}ponding}$	=	the average ponding surface area of the practice (ft^2)
	=	0.5 x [(surface area at the top of the ponding volume) + (surface area at the bottom of the ponding volume)]
$d_{ponding}$	=	the maximum ponding depth of the practice (ft).

Refer to Sections BR-4.6 (Ponding Depth) and BR-4.7 (Side Slopes) for additional design considerations.

Table BR-4. Maximum Ponding Surface Area to Soil Media Surface Area Ratios[1]

Surface Ponding Volume	Surface Ponding Depth (ft.)	Maximum Ratio of Surface Areas
At least 50% of Design Volume	< 1	1.5
At least 70% of Design Volume	≥ 1	1.25

[1]Defined as the ratio of the ponding surface area measured at the bottom of the ponding depth to the soil media surface area measured at the top of the soil media.

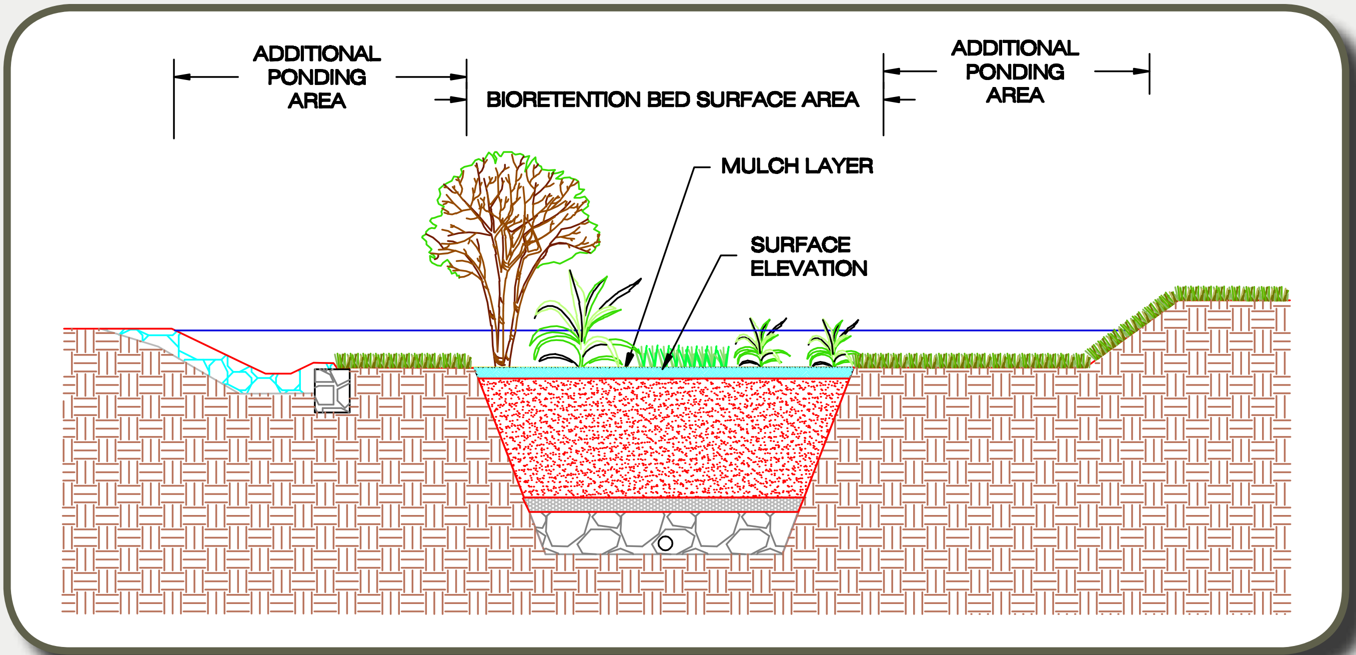

Figure BR-8. Typical section of Bioretention with additional surface ponding area

Step 3: Verify Total Design Volume:

The designer should verify that the combination of surface ponding volume and soil media and gravel storage volume is adequate to manage the Design Volume. The storage volume of the soil media and gravel is within the void spaces, referred to as porosity (η). The accepted porosity values for the storage components are illustrated in Figure BR-9 and listed below:

Surface Ponding	= ηponding	= 1.0
Soil Media	= ηmedia	= 0.25
Underdrain Gravel	= ηgravel	= 0.40

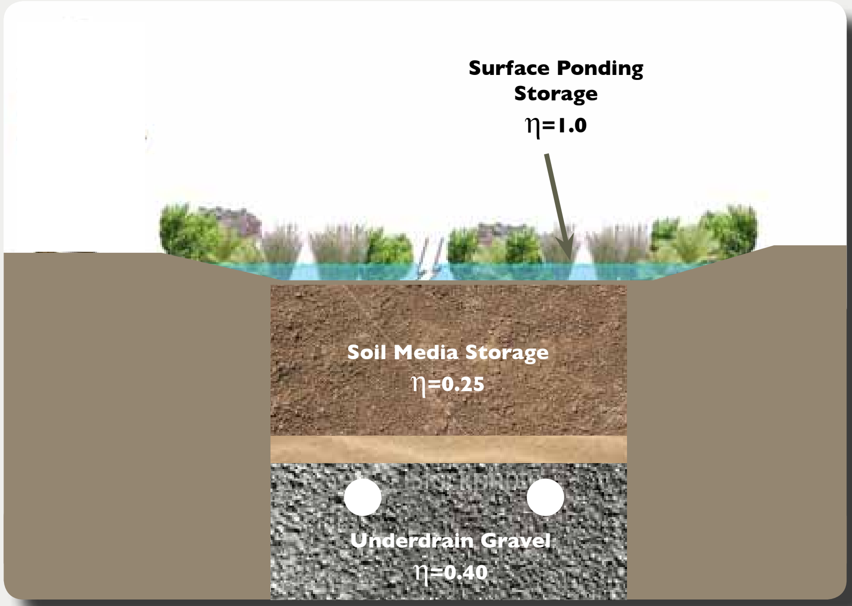

Figure BR-9. Typical Bioretention Section with Porosity (n) Values for Volume Computations

The total Design Volume of the practice can be computed using **Equation 4.2.**

Equation BR-2. Bioretention Design Volume

$$Dv_{practice} = SA_{bottom} \times [(d_{media} \times \eta_{media}) + (d_{gravel} \times \eta_{gravel})] + (SA_{avg-ponding} \times d_{ponding})$$

Where:

$Dv_{practice}$ = total design storage volume of practice (cu. ft.)
SA_{bottom} = bottom surface area of practice (sq. ft.)
d_{media} = depth of the soil filter media (ft)
η_{media} = effective porosity of the soil filter media (typically 0.25)
d_{gravel} = depth of the underdrain and underground storage gravel layer(ft)
η_{gravel} = effective porosity of the gravel layer (typically 0.40)
$SA_{avg-ponding}$ = the average ponding surface area of the practice (ft^2)
$d_{ponding}$ = the maximum ponding depth of the practice (ft).

Note: For a Level 1 design (underdrains and no infiltration sump), the gravel storage must be positioned above the underdrain in order to count as available storage. In either case, different combinations of the depth of ponding, media, and/or gravel can be evaluated for providing the required storage volume.

Equation BR-2 is conservative in that it assumes there are no subsurface side slopes. If a geotechnical evaluation determines that side slopes are required for the excavation or for long term stability, **Equation BR-2** can be modified to include the average surface areas of the various component layers as follows:

Equation 4.3. Bioretention Design Storage Volume with Subsurface Side Slopes

$$Sv_{practice} = [(SA_{avg-media} \ x \ d_{media} \ x \ n_{media}) + (SA_{avg-gravel} \ x \ d_{gravel} \ x \ n_{gravel}) + (SA_{avg-ponding} \ x \ d_{ponding})]$$

Step 4: Other Design Features:

The remainder of Section **BR-4 (Design Criteria)** provides guidelines for other design components of Bioretention (e.g., pretreatment, geometry) to ensure performance and longevity.

BR-4.2. Bioretention Sizing for Larger Storms (Local Detention Criteria)

The Design Volume can be counted toward storage that may be required to comply with local peak flow or detention requirements on small or moderately-sized sites. Designers may be able to create additional storage by expanding the surface ponding footprint (see above) or by incorporating subsurface storage with additional gravel or storage chambers.

It should be noted that all site designs should include provisions for safe conveyance of larger flows either contained within properly sized pipe or channel systems, or as overland flood routing to a receiving waterbody so as to minimize public safety risks and property damage. While some detention storage credit can be realized by oversizing runoff reduction practices such as Bioretention (which may reduce the size or footprint of downstream detention ponds), drainage system design and flood routing should use a conservative approach and be based on the expected peak rate of discharge from the larger storm events without any downsizing credited to runoff reduction.

BR-4.3. Pretreatment

Pre-Treatment is Essential

Pre-treatment of runoff entering Bioretention areas is necessary to trap coarse sediment particles before they reach and prematurely clog the filter bed. Pre-treatment measures must be designed to evenly spread runoff across the entire width of the Bioretention area. Pre-treatment is essential to prolong the life of the practice and ensure long-term performance. At the discretion of the local plan reviewer, full pre-treatment as detailed in this specification may not be necessary for practices with small drainage areas (e.g., less than ¼ acre).

Several pre-treatment measures are feasible, depending on the type of the Bioretention practice and whether it receives sheet flow, shallow concentrated flow or deeper concentrated flows. **Figure BR-10** shows typical pretreatment options for Bioretention. For pre-treatment structures at the edge of pavement (e.g., grass filter strips, gravel diaphragms, flow splitters), it is important that there be a 2 to 4 inch drop from the edge of pavement to the top of the grass or stone in the pre-treatment structure. This is to prevent accumulation of debris and subsequent clogging at the point where runoff is designed to enter the pre-treatment structure (see **Figure BR-11**).

Figure BR-10. Examples of Pre-Treatment Applicable to Bioretention

Grass strips that are perpendicular to incoming sheet flow extend from the edge of pavement (with a slight drop of 2 to 3 inches at the pavement edge) to the bottom of the Bioretention basin at a 5:1 slope or flatter.

A Pre-Treatment Cell is located at piped inlets or curb cuts leading to the Bioretention area. It has a storage volume equivalent to at least 15% of the total storage volume (inclusive). The cell may be formed by a timber check dam (pictured), stone check dam, or an earthen or rock berm. Pretreatment cells do not need underlying engineered soil media, in contrast to the main Bioretention cell (Source: Horsley Witten Group).

A **Grass Swale** can be used to convey flow to the Bioretention cell and provide pre-treatment. See **Specification 4.2.5** for design specifications.

A **Gravel Diaphragm** located at the edge of the pavement should be oriented perpendicular to the flow path to pre-treat lateral runoff, with a 2 to 4 inch drop from the pavement edge to the top of the stone. The stone must be sized according to the expected rate of discharge.
(Source: Beckley Sanitary Board)

The **Gravel or Stone Flow Spreader** is located at curb cuts, piped inlets, downspouts, or other concentrated inflow points. The gravel or stone should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the basin.

An approved **Proprietary Device** with demonstrated capability of reducing sediment and hydrocarbons may be used to provide pre-treatment.

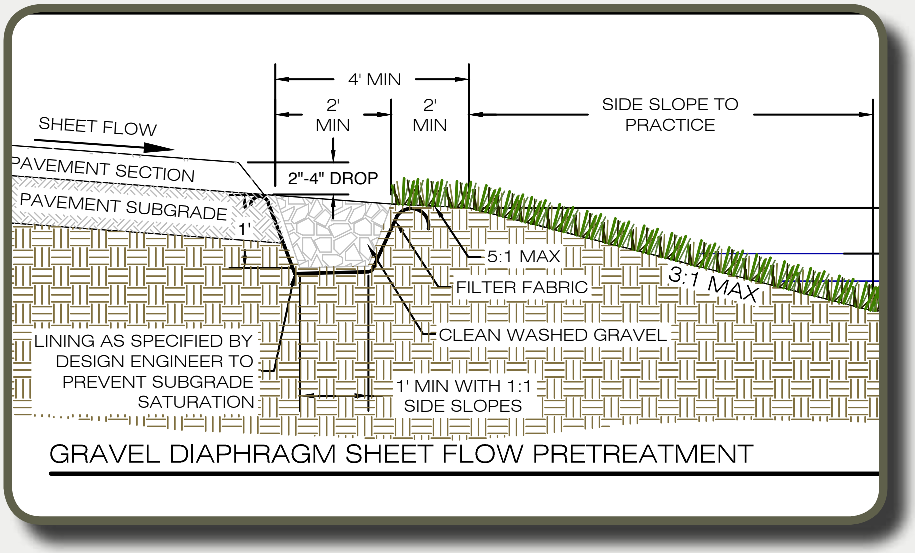

Figure BR-11. Typical Detail for Pre-Treatment at Pavement Edge – A 2 to 4 inch drop from the pavement to the top of stone helps to prevent clogging.

BR-4.4. Conveyance and Overflow

There are two basic design approaches for conveying runoff into, through, and around Bioretention practices (see **Figure BR-12**):

1. **Off-line:** Flow is split or diverted so that only the design storm or design flow enters the Bioretention area. Larger flows by-pass the Bioretention treatment and do not pass over the filter bed or through the facility. Additional flow is able to enter as the ponded water draws down by filtering through the soil media. Off-line designs can be accomplished by establishing a maximum ponding depth (at which point higher flows are diverted) or a flow diversion or flow splitter at or upgradient of the inlet. Off-line designs are usually the preferred option, especially for larger drainage areas (e.g., greater than 0.5 acres). This is particularly true if runoff is delivered by a storm drain pipe or is along the main conveyance system so that flows to do not overwhelm or damage the filter bed and plants.

2. **On-line:** All runoff from the drainage area flows into the practice. Flows that exceed the design capacity exit the practice via an overflow structure or weir. The following criteria apply to overflow structures:

- An overflow shall be provided within the practice to pass storms greater than the design storm storage to a stabilized conveyance or storm sewer system.
- The overflow should be controlled so that velocities are non-erosive at the outlet point (i.e., to prevent downstream erosion).
- Common overflow systems within Bioretention practices consist of an inlet structure, where the top of the structure is placed at the maximum ponding depth of the Bioretention area (6 to 18 inches above the filter bed surface).
- The overflow capture device should be scaled to the application – this may be a landscape grate or yard inlet for small practices or a commercial-type structure for larger installations.

It should be noted that both types of design approaches require attention to safe conveyance of larger flows in adequate conveyances and with adequate freeboard to a receiving waterbody. Drainage design should be based on expected peak discharges assuming that upstream practices may fail and/or provide marginal storage during larger events. These concerns should be addressed in a plan's overall drainage approach.

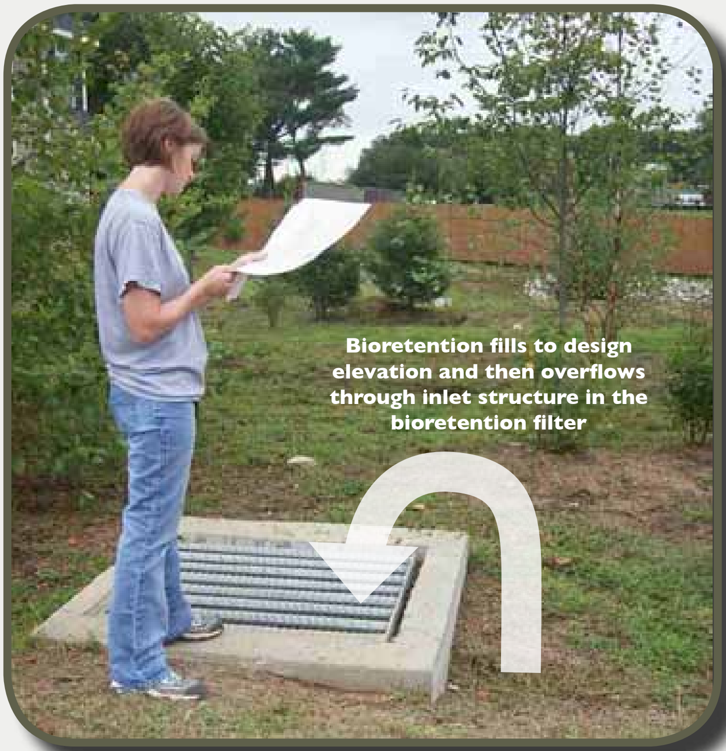

Figure BR-12. Top: Example of an off-line design where only the design volume goes to the Bioretention cell. This can also be accomplished with diversions or flow splitters upgradient from the cell. Bottom: Example of an "on-line" design where all the flow enters the Bioretention, and flows that exceed the design elevation overflow into a structure within the practice.

BR-4.5. Design Geometry

Bioretention basins must be designed with an internal flow path geometry such that the treatment mechanisms provided by the Bioretention are not bypassed or short-circuited. In order for these Bioretention areas to have an acceptable internal geometry, the "travel time" from each inlet to the outlet should be maximized by locating the inlets and outlets as far apart as possible. In addition, incoming flow must be distributed as evenly as possible across the entire filter surface area.

BR-4.6. Ponding Depth

The recommended surface ponding depth is 6 to 12 inches. Ponding depths can be increased to a maximum of 18" for management of larger storms.

Limit Applications of 18" Ponding

If an 18 inch ponding depth is used, the design must carefully consider issues such as safety, aesthetics, the viability and survival of plants, and erosion and scour of side slopes. The depth of ponding in the Bioretention area should never exceed 18". Shallower ponding depths (6 to 12 inches) are strongly recommended for all Bioretention areas in high visibility, commercial, residential, and other areas with foot traffic. The 18" ponding depth may be appropriate for larger-scale commercial, industrial, or institutional settings.

BR-4.7. Side Slopes

Side slopes should be 3:1 or flatter. In highly urbanized or space constrained areas, a drop curb design or a precast structure can be used to create stable, vertical side wall. For safety purposes, these drop curb designs should not exceed a vertical drop of more than 12 inches.

BR-4.8. Soil Media

The soil media is perhaps the most important element of a bioretention facility in terms of long-term performance. The following are key factors to consider in determining an acceptable soil media mixture.

- **General Soil Media Composition.** The recommended bioretention soil mixture is generally classified as a loamy sand on the USDA Texture Triangle, with the following composition (see also **Table BR-5**):
  - o 70% to 88% sand;
  - o 8% to 26% topsoil; and
  - o 3% to 5% organic matter (aged compost).

The goal of the mixture as described above is to create a soil media that maintains long-term permeability while also providing enough nutrients to support plant growth. The initial permeability of the mixture will exceed the desired long-term permeability of greater than 1 to 2 in./hr. The limited amount of topsoil and organic matter is considered adequate to help support initial plant growth, and it is anticipated that the gradual increase of organic material through natural processes will continue to support growth while decreasing gradually the permeability. Finally, the root structure of maturing plants and the biological activity of a self-sustaining organic content will maintain sufficient long term permeability as well as support plant growth without the need for fertilizer inputs.

Of equal importance is the source and composition of the materials. In addition to meeting the criteria noted in **Table BR-5**, the following criteria should govern the selection of materials for soil media mixes:

- Media components from land uses with specific history and/or prior land use related to biosolids or organic waste disposal, brownfields or superfund sites are prohibited.
- Sand should be a silica-based open graded coarse sand. Limestone parent material is prohibited. Recycled, pulverized glass may be used as a local option, provided the local program authority undertakes testing to verify that the product complies with the standards for sand in this specification (e.g., particle size distribution). Art glass or any glass sources that contain heavy metals should be prohibited from being included in the source material.
- Topsoil composition should consist of material classified as Loamy sand or Sandy loam as defined by the USDA textural classification triangle.
- Organic matter should be well aged and free of viable weed seeds, debris, and stable with regard to oxygen consumption and carbon dioxide generation. (Refer to **Appendix D** of this manual).

It may be advisable to start with an open-graded coarse sand material and proportionately mix in topsoil that will likely contain anywhere from 30% to 50% soil fines (sandy loam, loamy sand) to achieve the desired ratio of sand and fines. The exact composition of organic matter and topsoil material will vary, making particle size distribution and the recipe for the total soil media mixture difficult to define in advance of evaluating the available material. Therefore, it is highly recommended that filter media be obtained from a qualified vendor that can verify conformance with the media composition and standards in this specification. If media is mixed from available on-site material, a qualified individual should test the mixture to ensure conformity to this specification. **Table BR-5** outlines soil media testing standards that qualified vendors (or soil media mixed and tested on-site) should adhere to.

The particle size distribution of the sand and top soil material is extremely important for long term performance of the bioretention system. There have been issues of premature clogging and/or failure of the media when the sand/topsoil combination contains too high a fraction of fines. Given that the media mix is primarily sand, it is worth paying special attention to the sand specification and ensuring that the particle size distribution represents coarse sand. This is also important for locally-approved sand derived from recycled or pulverized glass.

The specification for coarse sand provided in **Table BR-5** allows less material passing the smaller sieves, and also provides for an Effective Particle Size and Uniformity Coefficient that encourages coarser sand.

Table BR-5. Soil Media Criteria and Testing for Bioretention

<table>
<tr><th>Soil Media Criterion</th><th>Description</th><th colspan="3">Standard(s)</th></tr>
<tr><td>General Composition</td><td>Soil media must have the proper proportions sand, fines, and organic matter to promote plant growth, drain at the proper rate, and filter pollutants</td><td colspan="3">70% to 88% sand;
8% to 26% top soil; and
3% to 5% organic matter (aged compost)</td></tr>
<tr><td rowspan="2">Sand</td><td rowspan="2">Silica based coarse aggregate[1]

Locally-approved pulverized glass may be substituted if the local authority undertakes testing to verify compliance with the specification and also lack of heavy metals</td><td>Sieve
3/8 in
No. 4
No. 8
No. 16
No. 30
No. 50
No. 100</td><td>Size
9.50 mm
4.75 mm 2.36
mm 1.18 mm
0.6 mm
0.3 mm
0.15 mm</td><td>% Passing
100
95 to 100
80 to 100
45 to 85
15 to 60
3 to 15
0 to 4</td></tr>
<tr><td colspan="3">Effective Particle size (D10) > 0.3mm
Uniformity Coefficient (D60/D10) < 4.0</td></tr>
<tr><td>Top Soil</td><td>Loamy sand or Sandy Loam</td><td colspan="3">USDA Textural Triangle</td></tr>
<tr><td>Organic Matter</td><td>Well aged, clean compost</td><td colspan="3">Appendix D</td></tr>
<tr><td>P-Index or Phosphorus (P) content</td><td>Soil media with high P levels will export P through the media and potentially to downstream conveyances or receiving waters</td><td colspan="3">P content = 7 to 23 mg/kg</td></tr>
</table>

Soil Media Criterion	Description	Standard(s)
Cation Exchange Capacity (CEC)	The CEC is determined by the amount of humus or organic matter. Higher CEC will promote pollutant removal	CEC > 10 milliequivalents per 100 grams
Infiltration Rate	This refers to the infiltration rate of the soil media, and not the underlying soil A minimum rate is required to allow the soil media to properly drain	Minimum Infiltration Rate = 1 – 2 inches/hour (most soil media will have much higher rates)
Soil Media Depth	The depth of soil media for various applications	Soil media depths for Level 1 and Level 2 design are specified in Table BR-1. If trees are included in the bioretention planting plan, tree planting holes in the filter bed must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees. In addition, higher proportions of topsoil (30%) and aged compost (20%) should be added to these planting holes compared to the rest of the soil media. Turf, perennials or shrubs should be used instead of trees to landscape shallower filter beds.

[1] *Many specifications for sand refer to ASTM C-33. The ASTM C-33 specification allows a particle size distribution that contains a large fraction of fines (silt and clay sized particles - < 0.05 mm). The smaller fines fill the voids between the larger sand sized particles, resulting in smaller and more convoluted pore spaces. While this condition provides a high degree of treatment, it also encourages clogging of the remaining void spaces with suspended solids and biological growth, resulting in a greater chance of a restrictive biomat forming. By limiting the fine particles allowed in the sand component, the combined media recipe of sand and the fines associated with the soil and organic material will be less prone to clogging, while also providing an adequate level of filtration and retention.*

BR-4.9. Surface Cover

The surface cover for Bioretention is variable and depends on the landscape context (e.g., highly-visible site versus less visible; site that will have routine mowing versus managed landscapes). The choice of surface cover also will influence the intensity of long-term maintenance activities (see Section BR-8). In general, the surface cover options are listed below.

- **Mulch**. A 2- to 3-inch layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, and pre-treats runoff before it reaches the filter media. Shredded hardwood bark mulch, aged for at least 6 months, makes a very good surface cover, as it retains a significant amount of pollutants and typically will not float away.

- **Alternative to Mulch Cover.** In some situations, designers may consider alternative surface covers such as turf, native groundcover, erosion control matting (coir or jute matting), river stone, or pea gravel. The decision regarding the type of surface cover to use should be based on function, cost and maintenance. Stone or gravel are not recommended in parking lot applications, since they increase soil temperature and have low water holding capacity.

- **Media for Turf Cover.** One adaptation suggested for use with turf cover is to design the filter media primarily as a sand filter with organic content only at the top. Leaf compost tilled into the top layers will provide organic content for the vegetative cover. If grass is the only vegetation, the ratio of organic matter in the filter media composition may be reduced.

BR-4.10. Underdrains

Many Bioretention designs will require an underdrain. **Table BR-6** provides general guidance for when to use an underdrain and the soil testing requirements for certain conditions.

Table BR-6. Guidance for Using Underdrains

	A/B Soils	C/D Soils
Drainage Area ≤ 0.5 acre	No underdrain needed	Use underdrain; no calculation needed for 48-hour dewatering. Use 12 inches or greater of underdrain stone
Drainage Area > 0.5 acre	Conduct soil infiltration test as per Appendix B of this Manual. No underdrain needed if field-tested rate > 0.5 inches per hour	Use underdrain. If using infiltration sump (see below), design to dewater design volume within 48 hours; for a 12 inch sump, the in-situ soils shall have a field verified infiltration rate ≥ 0.25 inches/hour (Note: HSG C soils can range from 0.1 to 3 in./hr.)

The underdrain should be a 4- or 6-inch perforated schedule 40 PVC pipe (or equivalent corrugated HDPE for small Bioretention practices) with 3/8-inch perforations at 6 inches on center. The underdrain should be encased in a layer of clean, washed ASTM D448 No. 57 stone. The underdrain should be sized so that the Bioretention practice fully drains within 48 hours.

Each underdrain should be located no more than 20 feet from the next pipe.

All Bioretention practices should include at least one observation well and/or cleanout pipe. The observation wells should be tied into any Ts or Ys in the underdrain system, and should extend upwards to be flush with the surface, with a vented cap.

BR-4.11. Infiltration Sump or Upturned Elbow (Level 2 Extended Filtration Design with Less Than 24 inches of Soil Media Depth)

An elevated underdrain configuration should be used to promote greater runoff reduction for Bioretention that has less than the minimum soil media depth and/or to boost runoff reduction performance for other designs, such as adding storage to meet local detention requirements (see **Figure BR-6**). In cases where limited head is a site constraint and the bioretention practice must be designed to be relatively shallow (e.g., depth to bedrock, relatively flat sites, or other factors), an upturned elbow underdrain design can be used to achieve the Level 2 design and enhanced runoff reduction (**Figure BR-7**).

The infiltration sump or upturned elbow should be installed to create a storage layer below the underdrain or upturned elbow invert. The bottom of the infiltration sump must be at least 2 feet above the seasonally high water table. The infiltration sump should be sized so that the Design Volume drains within 48 hours (see **Appendix B** of this Manual). This will depend on the Design Volume, the depth of the infiltration sump, and the presumed infiltration rate of the underlying soil. In general, a 12 inch infiltration sump can be used where the underlying infiltration rate is 0.25 inches per hour or greater. This should be field verified. Also, procedures to protect the infiltrative capacity of the soils during construction, and enhancing the infiltrative capacity before backfilling the soil media (such as roto-tilling or scarifying the surface) should be specified on the construction plans.

The inclusion of an infiltration sump is not permitted for designs with an impermeable liner (e.g., for karst or hotspot applications). In fill soil locations, geotechnical investigations are required to determine if the use of an infiltration sump is permissible and will not lead to the possibility of soil slips.

BR-4.12. Choking Layer

The choking layer is installed on top of the underdrain layer and below the soil media layer. This consists of a layer of choker stone (typically ASTM D448 No.8 or No.89 washed gravel). The depth of the choker layer should be 1 inch of choker stone for every 1 foot of soil media. For instance, 3 feet of soil media depth would have 3 inches of choker stone.

In lieu of the choking layer, designers have the option of using a needle-punched, non-woven geotextile fabric with a flow rate of > 110 gal./min./sq. ft. placed between the underdrain and the soil media layers. This may be a desirable option if available head or depth to water table or bedrock are site constraints. However, this option should only be used when the choking layer cannot fit into the practice.

BR-4.13. Underground Storage Layer (optional)

For Bioretention systems with an underdrain, an underground storage layer consisting of chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer to increase storage for larger storm events, control of which may be required by local detention or drainage regulations. The depth and volume of the storage layer will depend on the target storage volumes needed for local storage or detention criteria.

BR-4.14. Filter Fabric (optional)

Woven, monofilament filter fabric may be placed on the side slopes and/or in narrow strips (e.g., 2 feet wide) on top of the underdrain layer directly above underdrain pipes only. Filter fabric should not be used if trees will be planted in the filter bed surface. While there are many options for filter fabric, the design objective is to maintain hydraulic capacity while restricting the movement of sediment into the underdrain layer.

Do Not Use Filter Fabric over the Entire Underdrain Layer

In no case shall filter fabric be used to cover the entire underdrain layer as a substitute for the choker layer. The use of filter fabric between the soil media and underdrain stone has been a source of clogging with past installations.

BR-4.15. Impermeable Liner

This material should be used only for appropriate hotspot or karst designs, small-scale practices that are located near building foundations, or in appropriate fill applications where deemed necessary by a geotechnical investigation. Designers should use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile.

BR-4.16. Signage

Bioretention units in highly visible areas (e.g., schools, parks, urban settings, government buildings) should be stenciled or otherwise permanently marked to designate it as a stormwater management facility.The stencil or plaque should indicate (1) its water quality purpose, (2) that it may pond briefly after a storm, and (3) that it is not to be disturbed except for required maintenance.

BR-4.17. Bioretention Landscaping Criteria

Landscaping is critical to the function and performance of Bioretention areas. It is recommended that the planting plan be prepared by a qualified landscape architect or horticulturalist who has the expertise to design a plan tailored to site-specific conditions, including landscape context, microclimates, water velocity, planting zones, potential extended ponding time, and maintenance schedule.

The Bioretention landscaping plan should include the following elements:

- Clear delineation of planting area(s), mulched areas, accent stones, river rock beds, and other landscape elements.
- Plant list with Latin and common names, size of plant material [quart containers, #1 (1 gallon container), #2 (2 gallon), 2.5" caliper tree, etc.], quantities, and any specifics desired, such as multi-stem or single stem.
- List and quantities for other materials (e.g., rock, erosion control matting).
- Note whether plant substitutions are permitted, and who can authorize substitutions.
- Construction notes about handling and watering of plants and other materials during construction and construction sequence for landscaping elements.

- Maintenance information, such as:
  - Instructions for initial watering (e.g., first growing season after installation)
  - Punch list items (e.g., erosion, damaged plants) and an identified responsible party for adjustments or repairs after the first three significant rain events.
  - Care and replacement of plant materials for a specified timeframe (e.g., 1 year after installation). It is recommended that construction contracts include a care and replacement warranty to ensure that vegetation is properly established and survives through at least the first growing season following construction.
    - Maintenance tasks and frequencies (see **Section BR-8**).
    - The intended plant community in future years. This will help the party responsible for maintenance to know how to cut, prune, replace, supplement, and otherwise maintain the landscaping to achieve the desired plant community and aesthetics. Photos, photo simulations, and/or other graphics showing the desired plant community at years 1, 3, 5, 10 and beyond are also helpful for long-term maintenance.

Native plant species are preferred over non-native species, to include "native selections" and cultivars. Some ornamental species may be used if they are proven to be "sustainable" and are not aggressive or invasive. Some popular native species which work well in Bioretention areas and that are commercially available can be found in **Appendix F.** Internet links to more detailed Bioretention plant lists developed in the Chesapeake Bay and the Mississippi River Basin regions are provided below:

- **West Virginia Division of Natural Resources**
  http://www.wvdnr.gov/
- **Wildlife Diversity Program and Natural Heritage Program (WVDNR)**
  http://www.wvdnr.gov/wildlife/wdpintro.shtm
- **West Virginia Native Plant Society**
  http://www.wvnps.org/index.html
- **West Virginia Nursery and Landscape Association**
  http://www.wvnla.org/
- **Native Plant Database - Lady Bird Johnson Wildflower Center**
  http://www.wildflower.org/plants/
- **List of Native Plants by each State (USDA):**
  http://plants.usda.gov/checklist.html
- **Invasive species list**
  http://invasipedia.org/

Planting choices for Bioretention areas (both urban and non-urban) should be selected based on the level of landscape maintenance which will be devoted to the Bioretention. Plant selection differs if the area will be frequently mowed, pruned, and weeded, in contrast to a site which will receive minimum annual maintenance. In areas where less maintenance will be provided, consider the "meadow" or "wildflower" landscaping model. In certain cases, site owners or managers may wish to have managed turf as the ground cover that can be mowed along with other turf areas on the site. While this is allowable, it is not the recommended planting type for bioretention. If used, turf cover should be integrated with herbaceous, shrub, and/or tree zones.

The Objective of the Planting Plan is to cover the Surface of the Filter Bed

The primary objective of the planting plan is to cover the surface area as quickly as possible so that the plants establish their roots in order to promote the beneficial biological activity in the soil media. Herbaceous or ground covers plantings are more beneficial than more trees and shrubs because they establish and spread quickly throughout the filter bed.

Additional guidance for Bioretention landscaping is provided below:

- Woody vegetation should not be located at points of inflow.
- "Wet footed" species (OBL or FACW) should be planted near the center, whereas upland species (FACU and UPL) do better planted near the edge.
- Shrubs and herbaceous vegetation should generally be planted in clusters and at higher densities (i.e., shrubs at approximately 6 to 10 feet on-center and herbaceous plantings at approximately 1 to 1.5 feet on-center (depending on the species).
- Trees should not be planted directly above underdrains, but should be located closer to the perimeter.
- If trees are part of the planting plan, a tree density of approximately one tree per 250 square feet, or 15 feet on-center, is recommended.
- Designers should note that planting holes for trees must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees. This applies even if the remaining soil media layer is shallower than 4 feet.
- If trees are used, plant shade-tolerant ground covers within the drip line (depending on species).
- If the Bioretention area is to be used for snow storage, or will potentially receive runoff from snowmelt, the designer may want to consider salt-tolerant, herbaceous perennials.

BR-5. Materials Specifications

Recommended material specifications for Bioretention areas are shown in **Table BR-7**.

Table BR-7. Bioretention Material Specifications

Material	Specification	Notes
Filter Media	• 70%-88% sand • 8%-26% top soil • 3%-5% organic matter in the form of leaf compost • Supplied by qualified vendor • Refer to **Table BR-5** for specific media material composition	Minimum depth of 24 in.; 36 in. recommended; (18 in. if an infiltration sump is used) The volume of filter media used should be based on 110% of the plan volume, to account for settling or compaction.
Filter Media Testing	Between 7 and 21 mg./kg. of P in the soil media. CECs greater than 10	Qualified vendors should test media in batches.
Mulch Layer	Use aged, shredded hardwood bark mulch	Lay a 2 to 3 in. layer on the surface of the filter bed.
Alternative Surface Cover	Use river stone or pea gravel, coir and jute matting, or turf cover.	Lay a 2 to 3 in. layer to suppress weed growth.
Top Soil For Turf Cover	Loamy sand or sandy loam texture, with less than 5% clay content, pH corrected to between 6 and 7, and an organic matter content of at least 2%.	3 inches tilled into surface layer.
Filter Fabric (optional)	Woven monofilament fabric or non-woven geotextile as per AASHTO M-288 (do not use silt fence)	Apply only to the side slopes and, optionally, in a 2 ft. wide strip directly above the underdrain pipes.
Choking Layer	Layer of choker stone (typically No.8 or No.89 washed gravel), which is laid over the underdrain stone at a depth of 1 in. of choker stone for every 1 ft. of overlying soil media. An alternative is needle-punched, non-woven geotextile with the flow rate of > 110 gal./min./sq. ft. (ONLY if stone choking layer cannot fit into the practice).	

Material	Specification	Notes
Underdrain Stone	1-in. diameter stone should be double-washed and clean and free of all fines (e.g., ASTM D448 No. 57 stone).	12 in. depth
Infiltration Sump (As Needed)	1-in. diameter stone should be double-washed and clean and free of all fines (e.g., ASTM D448 No. 57 stone).	Designed to drain the sump design volume (gravel layer below underdrain or with an upturned elbow) within 48 hours; can use standard 12 in. depth below the underdrain invert if soil at the infiltration sump elevation has a verified infiltration rate ≥ 0.25 in./hr.
Storage Layer (optional)	To increase storage for larger storm events, chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer	
Impermeable Liner (optional)	Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile. Note: This is used only for stormwater hotspots, Karst, and small practices near building foundations, or in fill soils as determined by a geotechnical investigation.	
Underdrains, Cleanouts, and Observation Wells	Use 4- or 6-in. rigid schedule 40 PVC pipe (or equivalent corrugated HDPE for small Bioretention practices), with 3/8-in. perforations at 6 in. on center; each underdrain should be located no more than 20 feet from the next pipe.	Lay the perforated pipe under the length of the Bioretention cell, and install non-perforated pipe as needed to connect with the storm drain system or to daylight in a stabilized conveyance. Install Ts and Ys as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.
Plant Materials	See Section BR-4.17	Establish plant materials as specified in the landscaping plan and the recommended plant list.

BR-6. Design Adaptations

BR-6.1. Karst Terrain

Karst regions are found in much of the Ridge and Valley and Panhandle. Karst complicates both land development and stormwater design. While Bioretention areas produce shallower ponding than conventional stormwater practices (e.g., ponds and wetlands), infiltration designs (without an underdrain) are not recommended in any area with a moderate or high risk of sinkhole formation (Hyland, 2005). On the other hand, Level 1 designs (with an underdrain but NO infiltration sump) that meet separation distance requirements (3 feet) and possess an impermeable bottom liner should work well. In general, small-scale Bioretention and Bioretention basins with contributing drainage areas not exceeding one-half acre are preferred (compared to Bioretention with larger drainage areas), in order to prevent possible sinkhole formation. However, it may be advisable to increase standard setbacks to buildings.

BR-6.2. Steep Slopes

Bioretention can be used on sites with steep slopes, provided the following design issues are considered:

- If the site has steep slopes, the site grading should provide for a relatively flat area immediately surrounding the Bioretention practice. The recommendation is for slopes within 15 to 20 feet of the practice to be at a slope of 5% or less.
- Bioretention can be split into multiple cells to take advantage of relatively level areas on the site. Adequate conveyance should be provided between the cells.
- For designs that require a longitudinal slope, use the Water Quality Swale design (**Supplement 4.2.3.A**). Use check dams to flatten the longitudinal slope between the cells, with adequate conveyance and armoring (river stone or appropriate lining) between sections.
- For designs with moderate to steep slopes surrounding the practice, additional engineering design should be applied at the inlets to pretreatment and the practice itself, ensuring that energy dissipaters and drops are engineered to create non-erosive flow conditions. Off-line designs (**Section BR-4.4**) are strongly encouraged.
- For practices near or adjacent to steep slopes, a geotechnical review may be needed to ensure that there will not be a slip or slope instability issue. This would be particularly relevant to practices that utilize an infiltration design or have an infiltration sump.

BR-6.3. Cold Climate and Winter Performance

Many different kinds of salting and sanding materials are applied in West Virginia during winter conditions. These can clog Bioretention areas if the proper design approach is not used, particularly for practices that treat road and highway runoff. In these cases, pre-treatment cells or separate upgradient sediment storage areas should be employed to try to keep as many of these materials as possible off of the filter bed.

Bioretention areas can be used for snow storage as long as an overflow is provided and they are planted with salt-tolerant, non-woody plant species. Tree and shrub locations should not conflict with plowing and piling of snow into storage areas.

While several studies have shown that Bioretention facilities operate effectively in winter conditions, it is a good idea to extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by one pipe size to reduce the freezing potential.

BR-6.4. Stormwater Retrofitting

Bioretention is one of the most versatile practices for retrofitting. Some of the chief considerations for retrofitting are space available to accommodate the practice and head available to tie underdrains into an existing drainage structure or to daylight. Many retrofit practices cannot meet the full sizing requirements outlined in **Section BR-4.1**, so it is important to define retrofit objectives and the desired Design Volume necessary to meet TMDL or watershed restoration goals.

For more information on retrofitting, see the Center for Watershed Protection's manual, Urban Stormwater Retrofit Practices (Schueler et al., 2007).

4.2.3 Bioretention

BR-7. Construction & Installation

BR-7.1. Erosion and Sediment Controls

Bioretention areas should be fully protected by appropriate and approved erosion and sediment control measures (e.g., silt fence, super silt fence, diversion dikes, and/or other approved measures to keep construction site runoff away from intended Bioretention areas (see WVDEP, 2006). Ideally, Bioretention should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment.

At the discretion of the plan approving authority, large Bioretention applications may be used as sediment traps or basins during construction. However, these must be accompanied by notes and graphic details on the erosion and sediment control plan specifying that (1) the maximum excavation depth of the trap or basin at the construction stage must be at least 1 foot higher than the post-construction (final) invert (bottom of the facility), and (2) the facility must contain an underdrain. The plan approving authority may authorize alternative means to ensure that the co-location of erosion control measures and permanent bioretention meets the design objectives of both erosion control and the ultimate bioretention practice. Some of the main objectives for bioretention are that the soil interface at the bioretention invert not be clogged with construction sediments, and that the geometry, slopes, and grading of the final bioretention practice adhere to the specification and good design practice.

The plan must also show the proper procedures for converting the temporary sediment control practice to a permanent Bioretention facility, including dewatering, cleanout and stabilization. Of course, in cases where the practices are co-located, the practice location would not be outside of the limits of disturbance.

Drainage Areas Should be Stabilized Before Installation of Underdrains & Soil Media

The #1 source of failure for Bioretention is installation too early during the construction process and/or lack of erosion control measures during installation. Construction sediment will readily clog underdrain stone and soil media. Drainage areas to Bioretention areas should be stabilized with vegetation prior to installation of these materials.

BR-7.2. Bioretention Installation

The following is a typical construction sequence to properly install a Bioretention basin. The construction sequence for Residential Rain Gardens (see Supplement 4.2.3.C) is more simplified. These steps may be modified to reflect different Bioretention applications or expected site conditions:

Step 1. Construction of the Bioretention area may only begin after the entire CDA has been stabilized with vegetation. It may be necessary to block certain curb or other inlets while the Bioretention area is being constructed. The proposed site should be checked for existing utilities prior to any excavation.

Step 2. The designer and the installer should have a preconstruction meeting, checking the boundaries of the CDA and the actual inlet elevations to ensure they conform to original design. Since other contractors may be responsible for constructing portions of the site, it is quite common to find subtle differences in site grading, drainage and paving elevations that can produce hydraulically important differences for the proposed Bioretention area. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the plan review/inspection authority.

Step 3. Temporary approved erosion and sediment controls are needed during construction of the Bioretention area to divert stormwater away from the Bioretention area until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the construction process. In cases where the Bioretention is co-located with erosion and sediment control practices (e.g., sediment traps), the conditions noted in Section BR-7.1 must be followed.

Step 4. Any pre-treatment cells should be excavated first and then sealed to trap sediments.

Step 5. Excavators or backhoes should work from the sides to excavate the Bioretention area to its appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the Bioretention area. Contractors should use a cell construction approach in larger Bioretention basins, whereby the basin is split into 500 to 1,000 sq. ft. temporary cells with a 10-15 foot earth bridge in between, so that cells can be excavated from the side.

Step 6. It may be necessary to rip the bottom soils to a depth of 6 to 12 inches to promote greater infiltration.

Step 7. If using a filter fabric, place the fabric on the sides of the Bioretention area with a 6-inch overlap on the sides. If an underdrain stone storage layer will be used, place the appropriate depth of No.57 stone on the bottom, install the perforated underdrain pipe, pack No.57 stone to 3 inches above the underdrain pipe. On top of the No.57 stone, add 2 inches of choker stone (No.8 or No.89 stone) and then 2 to 4 inches of construction sand as a filter between the underdrain and the soil media layer. If no stone storage layer is used, start with 6 inches of No.57 stone on the bottom, and proceed with the layering as described above.

Step 8. Deliver the soil media from an approved vendor, and store it on an adjacent impervious area or plastic sheeting. Apply the media in 12-inch lifts until the desired top elevation of the Bioretention area is achieved. Wait a few days to check for settlement, and add additional media, as needed, to achieve the design elevation.

Step 9. Prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly. Install any temporary irrigation.

Step 10. Place the surface cover in both cells (mulch, river stone or turf), depending on the design. If coir or jute matting will be used in lieu of mulch, the matting will need to be installed prior to planting (Step 9), and holes or slits will have to be cut in the matting to install the plants.

Step 11. Install the plant materials as shown in the landscaping plan, and water them during weeks of no rain for the first two months.

Step 12. If curb cuts or inlets are blocked during Bioretention installation, unblock these after the drainage area and side slopes have good vegetative cover. It is recommended that unblocking curb cuts and inlets take place after two to three storm events if the drainage area includes newly installed asphalt, since new asphalt tends to produce a lot of fines and grit during the first several storms.

Step 13. Conduct the final construction inspection (see below), then log the GPS coordinates for each Bioretention facility and submit them for entry into the local maintenance tracking database.

An example construction phase inspection checklist is available in Appendix A of the Manual.

4.2.3 Bioretention

BR-8. Maintenance Criteria

Consider Maintenance during the Design Process

One of the critical maintenance issues is to understand how design choices influence the long-term maintenance obligations of a practice. The context of the site and maintenance capabilities of the owner should be considered during the design process. **Table BR-8** notes several design issues that can result in lower or higher levels of maintenance.

Table BR-8. Design Decisions That Influence Long-Term Maintenance Activities

Design Feature	Lower Maintenance	Higher Maintenance
Surface Cover (Section BR-4.9)	Grass cover that can be mowed; recommend interspersing with trees; Meadow or wildflower cover with native grasses	Mulch cover with perennials and shrubs that must be weeded routinely and have the mulch replaced
Ponding Depth (Section BR-4.6)	Shallow ponding at 6 in. to 12 in. creates less stress on plants and side slopes	> 12 in. may lead to erosion of slide slopes and stress on plants
Pre-Treatment (Section BR-4.3)	Pre-treatment cell or grass filter strips with a 2 in. to 4 in. drop from the pavement surface	Curb cuts that accumulate grit and debris that must be removed periodically in order to prevent clogging of inlet
Conveyance (Section BR-4.4)	Off-line designs where only the design volume enters the practice; higher flows are diverted to the storm sewer system and/or adequate conveyance.	On-line designs where all flows enter the practice; higher flows exit through an overflow that is internal to the practice. High flows may create periodic damage to structural elements as well as increased routine maintenance, such as replacing mulch or damaged vegetation.

Maintenance agreements must be executed between the owner and the local authority. The agreements will specify the property owner's primary maintenance responsibilities and authorize local agency staff to access the property for inspection or corrective action in the event that proper maintenance is not performed.

All Bioretention areas must be covered by a drainage easement to allow inspection and maintenance by local authority staff.

When Residential Rain Gardens are applied on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to modified maintenance agreements as described above.

Maintenance of Bioretention areas should be integrated into routine landscape maintenance tasks. If landscaping contractors will be expected to perform maintenance, their contracts should contain specifics on unique Bioretention landscaping needs, such as maintaining elevation differences needed for ponding, proper mulching, sediment and trash removal, and limited use of fertilizers and pesticides.

Maintenance tasks and frequency will vary depending on the size and location of the Bioretention, the landscaping template chosen, and the type of surface cover in the practice. A generalized summary of common maintenance tasks and their frequency is provided in **Table BR-9**.

Table BR-9. Recommended Maintenance Tasks for Bioretention Practices

Maintenance Tasks	Frequency
▪ For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 1/2 in. of rainfall. Conduct any needed repairs or stabilization. ▪ Inspectors should look for bare or eroding areas in the CDS or around the Bioretention area, and make sure they are immediately stabilized with grass cover. ▪ One-time, spot fertilization may be needed for initial plantings. ▪ Watering is needed once a week during the first 2 months, and then as needed during first growing season (April-October), depending on rainfall. ▪ Remove and replace dead plants. Up to 10% of the plant stock may die off in the first year, so construction contracts should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.	Upon establishment
▪ Mowing of grass filter strips and Bioretention with turf cover ▪ Check curb cuts and inlets for accumulated grit, leaves, and debris that may block inflow	At least 4 times a year
▪ Spot weeding, trash removal, and mulch raking	Twice during growing season

Maintenance Tasks	Frequency
▪ Add reinforcement planting to maintain desired the vegetation density ▪ Remove invasive plants using recommended control methods ▪ Remove any dead or diseased plants ▪ Stabilize the CDA to prevent erosion	As needed
▪ Conduct a maintenance inspection ▪ Supplement mulch in devoid areas to maintain a 3 inch layer ▪ Prune trees and shrubs ▪ Remove sediment in pre-treatment cells and inflow points	Annually
▪ Remove sediment in pre-treatment cells and inflow points ▪ Remove and replace the mulch layer	Once every 2 to 3 years

The most common non-routine maintenance problem involves standing water. If water remains on the surface for more than 48 hours after a storm, adjustments to the grading may be needed or underdrain repairs may be needed. The surface of the filter bed should also be checked for accumulated sediment or a fine crust that builds up after the first several storm events. There are several methods that can be used to rehabilitate the filter. These are listed below, starting with the simplest approach and ranging to more involved procedures (if the simpler actions do not solve the problem):

- Open the underdrain observation well or cleanout and pour in water to verify that the underdrains are functioning and not clogged or otherwise in need of repair. The purpose of this check is to see if there is standing water all the way down through the soil. If there is standing water on top, but not in the underdrain, then there is a clogged soil layer. If the underdrain and stand pipe indicates standing water, then the underdrain must be clogged and will need to be cleaned out.
- Remove accumulated sediment and till 2 to 3 inches of sand into the upper 6 to 12 inches of soil.
- Install sand wicks from 3 inches below the surface to the underdrain layer. This reduces the average concentration of fines in the media bed and promotes quicker drawdown times. Sand wicks can be installed by excavating or augering (using a tree auger or similar tool) down to the top of the underdrain layer to create vertical columns which are then filled with a clean open-graded coarse sand material (ASTM C-33 concrete sand or similar approved sand mix for Bioretention media). A sufficient number of wick drains of sufficient dimension should be installed to meet the design dewatering time for the facility.
- Remove and replace some or all of the soil media.

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each Bioretention area. Example maintenance inspection checklists for Bioretention areas can be found in **Appendix A of the Manual**.

Supplement 4.2.3.A. Water Quality Swale (WQS)

WQS-1. Water Quality Swales

Water Quality Swales are essentially Bioretention cells that are configured as linear channels, usually have a longitudinal slope, often with check dams to break to swale in "cells," and are covered with turf, herbaceous plants (e.g., meadow grasses), or other surface material. See **Figure WQS-1** for typical applications. The design specifications for Water Quality Swales are the same as for Bioretention, except for the additional information contained within this appendix.

Figure WQS-1. Typical Applications for Water Quality Swales

Water Quality Swale with check dams along roadway

Water Quality Swale at edge of parking lot

Turf-covered Water Quality Swale with curb cuts and stone pre-treatment

Table WQS-1 describes the Level 1 and Level 2 design options for **Water Quality Swales a**nd the practice performance in terms of reducing the volume associated with one inch of rainfall on the site. **Table WQS-2** summarizes pollutant removal performance values for Level 1 and Level 2 designs. This is for the purpose of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans.

Table WQS-1. Water Quality Swale Design Levels: Descriptions & Performance

Design Level	Description	Applications	Performance[1]
Level 1	Basic Design • Swale longitudinal slope between 2 and 4% with use of check dams • Bottom width 2 to 4 ft. • Underdrain • At least 1.5 ft. of soil media depth, but less than 2.0 ft. • No infiltration sump below underdrain pipe(s)	See **Table BR-1** in main Bioretention specification Also, sites where slopes dictate use of practice with longitudinal slope or where this configuration better suits the site design.	55% volume reduction for the Design Volume of the practice[2]
Level 2	• Swale longitudinal slope between 0.5 and 2% with use of check dams • Bottom width 4 to 8 ft. Infiltration Design • No underdrain • Water infiltrates into the underlying soil within 48 hours. OR Extended Filtration Design • Underdrain • At least 2.0 ft. of soil media depth, OR • At least 1.5 ft. of soil media depth with stone sump below underdrain designed to drain Design Volume within 48 hours on suitable soils (e.g., limited on fill).		100% volume reduction for the Design Volume of the practice[2]

[1] *Performance achieved toward reducing one inch of rainfall*

[2] *Design Volume includes storage on the surface, within the soil media, and in the infiltration sump. The Design Volume can be 100% of that needed to meet the one-inch performance standard or some proportion of it when used in conjunction with other practices. See Section* ***BR-4.1*** *of the Bioretention specification for sizing details.*

Table WQS-2. Pollutant Removal Performance Values for Level 1 and 2 Design[1]

Design Level	Total Suspended Solids (TSS)	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)
Level 1	TSS = 65%	TP = 52% TN = 55%
Level 2	TSS = 90%	TP = 76% TN = 74%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008).

WQS-2. Typical Details

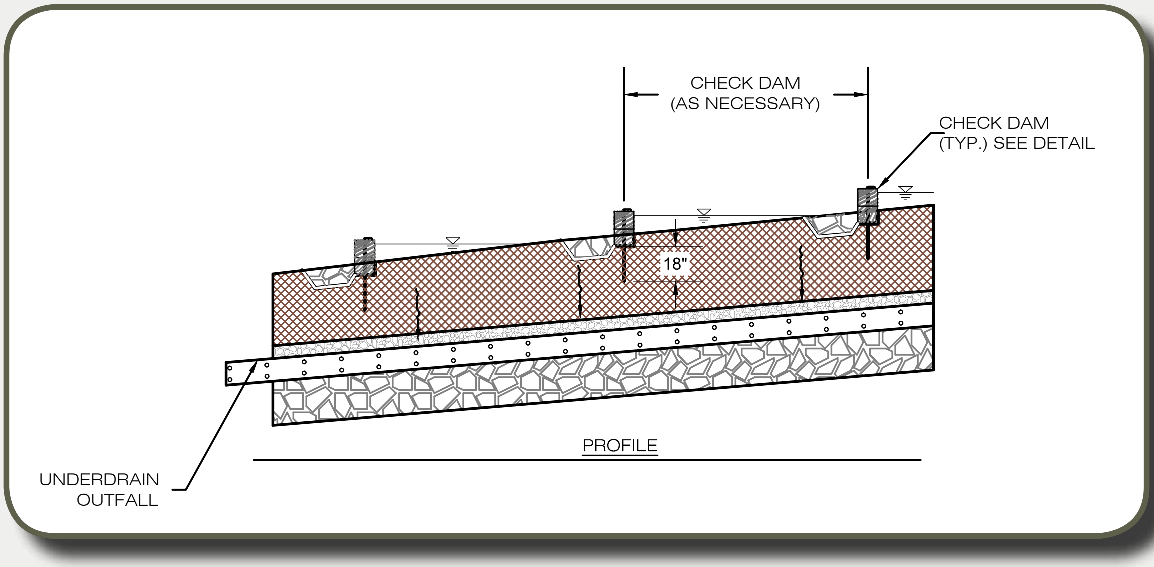

Figure WQS-2. Typical profile for Water Quality Swale with check dams

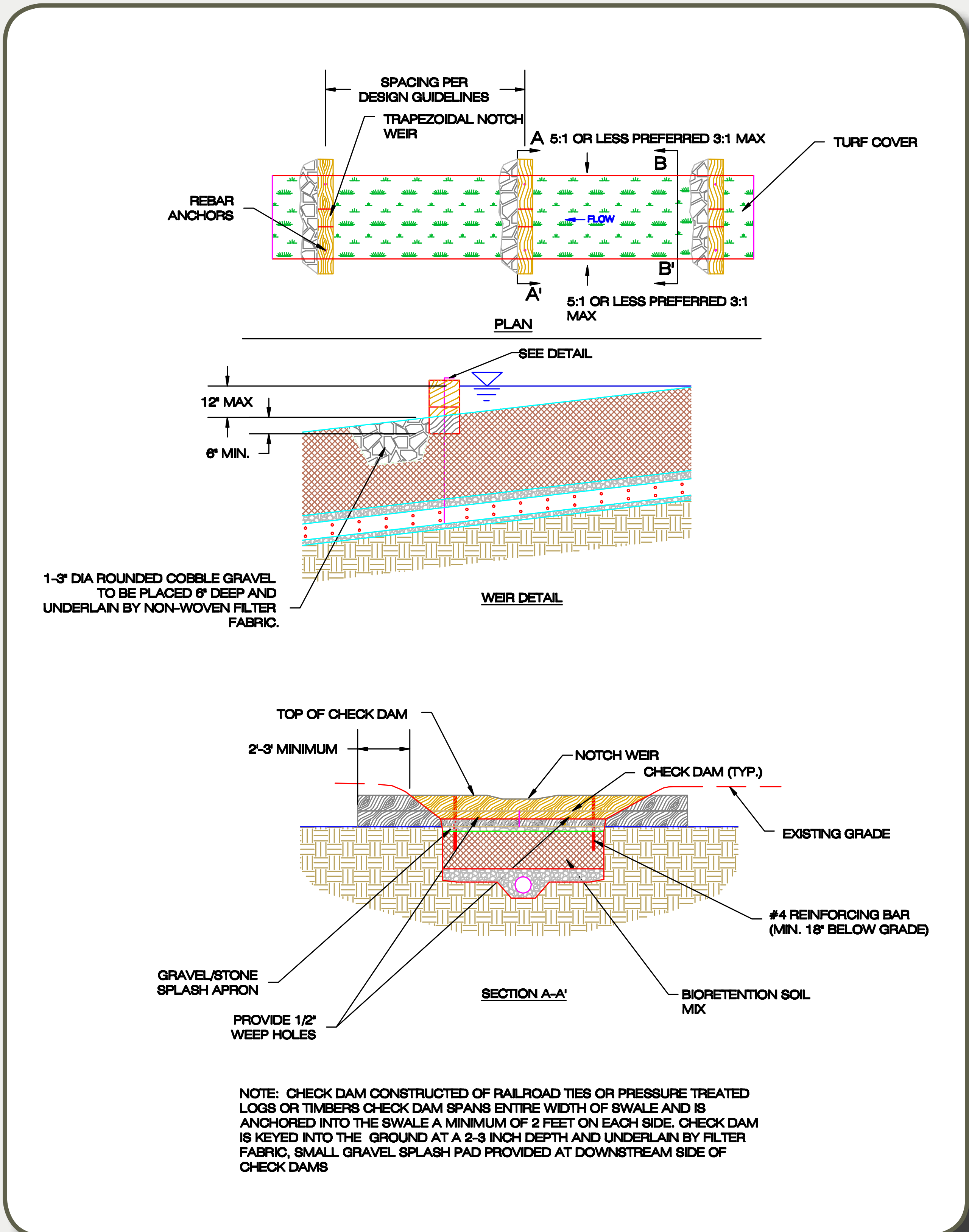

Figure WQS-3. Typical details for check dams

WQS-3. Sizing

The sizing for Water Quality Swales is the same as for Bioretention, except that the surface ponding volume is the volume captured behind the check dams, so must be calculated as wedge. The surface ponding requirements that apply to Bioretention (at least 50% of total design volume for ponding depths less than 1 foot and 70% for ponding depths of 1 foot or greater) do not apply to Water Quality Swales.

WQS-4. Side Slopes

The side slopes of Water Quality Swales should be no steeper than 3H:1V for maintenance considerations (i.e., mowing). Flatter slopes are encouraged where adequate space is available, to enhance pre-treatment of sheet flows entering the swale.

WQS-5. Conveyance

The bottom width and slope of a Water Quality Swale should be designed such that the velocity of flow from a one-inch rainfall will not exceed 3 feet per second. Check dams may be used to achieve the needed runoff reduction volume, as well as to reduce the flow velocity. Check dams should be spaced based on channel slope and ponding requirements, consistent with the criteria in **Table WQS-1**.

The swale should also convey the locally required design storms (e.g., 2- and 10-year storms) at non-erosive velocities with at least 3 inches of freeboard. The analysis should evaluate the flow profile through the channel at normal depth, as well as the flow depth over top of the check dams.

A Water Quality Swale may be designed as an off-line system, with a flow splitter or diversion to divert runoff in excess of the design capacity to an adjacent conveyance system. Alternately, strategically placed overflow inlets may be placed along the length of the swale to periodically pick up water and reduce the hydraulic loading at the downstream limits.

WQS-6. Check Dams

Check dams may be used for pre-treatment, to break up slopes, and to increase the hydraulic residence time in the channel. Design requirements for check dams are as follows:

- Check dams should be spaced based on the channel slope, as needed to increase residence time, provide design storm storage volume, or any additional volume attenuation requirements. In typical spacing, the ponded water at a downhill check dam should not touch the toe of the upstream check dam. More frequent spacing may be desirable in Water Quality Swales to increase the ponding volume.
- The maximum desired check dam height is 12 inches (for maintenance purposes). However, for some sites, a maximum of 18 inches can be allowed, with additional design elements to ensure the stability of the check dam and the adjacent and underlying soils. In these cases, the average ponding depth throughout the channel should be 12 inches.
- Armoring may be needed at the downstream toe of the check dam to prevent erosion.
- Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the channel bottom so as to prevent hydrostatic head from pushing out the underlying soils.
- Check dams must be designed with a center weir sized to pass the channel design storm peak flow (10-year storm event for man-made channels).
- Check dams should be composed of wood, concrete, stone, compacted soil, or other non-erodible material, or should be configured with elevated driveway culverts.
- Check dams should be constructed of a non-erosive material such as wood, stone, riprap, concrete, or compacted soil (with a stone spillway). All check dams should be underlain with filter fabric conforming to local design standards.
- Wood used for check dams should consist of pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.

Check dams for Water Quality Swales should be spaced to reduce the effective slope to the desired slope (see **Table WQS-1**), as indicated in **Table WQS-3**.

Table WQS-3. Typical Check Dam Spacing to Achieve Effective Channel Slope

Channel Longitudinal Slope	Spacing [1] of 12-inch High (max.) Check Dams [3, 4] to Create an Effective Slope of 2%	Spacing [1] of 12-inch High (max.) Check Dams [3, 4] to Create an Effective Slope of 0 to 1%
0.5%	–	200 ft.to –
1.0%	–	100 ft.to –
1.5%	–	67 ft.to 200 ft.
2.0%	–	50 ft.to 100 ft.
2.5%	200 ft.	40 ft.to 67 ft.
3.0%	100 ft.	33 ft.to 50 ft.
3.5%	67 ft.	30 ft.to 40 ft.
4.0%	50 ft.	25 ft.to 33 ft.
4.5% [2]	40 ft.	20 ft.to 30 ft.
5.0% [2]	40 ft.	20 ft.to 30 ft.

Notes:

[1] The spacing dimension is half of the above distances if a 6-inch check dam is used.

[2] Open channels with slopes greater than 4% require special design considerations, such as drop structures to accommodate greater than 12-inch high check dams (and therefore a flatter effective slope), in order to ensure non-erosive flows.

[3] All check dams require a stone energy dissipater at the downstream toe.

[4] Check dams require weep holes at the channel invert. Swales with slopes less than 2% will require multiple weep holes (at least 3) in each check dam.

Supplement 4.2.3.B Urban Bioretention (UB)

UB-1. Urban Bioretention

Urban Bioretention practices are similar in function to regular Bioretention practices except they are adapted to fit into "containers" within urban landscapes. Typically, Urban Bioretention is installed within an urban streetscape or city street right-of-way, urban landscaping beds, tree pits and plazas, or other features.

Urban Bioretention features hard edges, often with vertical concrete sides, as contrasted with the more gentle earthen slopes of regular Bioretention. These practices may be open-bottomed, to allow some infiltration of runoff into the sub-grade, but they generally are served by an underdrain.

Stormwater planters (also known as vegetative box filters or foundation planters) take advantage of limited space available for stormwater treatment by placing a soil filter in a container located above ground or at grade in landscaping areas adjacent to buildings and/or between buildings and roadways. The small footprint of the planter is typically contained in a precast or cast-in-place concrete vault. Stormwater planters combine an aesthetic landscaping feature with a functional form of stormwater treatment. They generally receive runoff from adjacent rooftop downspouts and are landscaped with plants that are tolerant to periods of both drought and inundation.

Extended tree boxes are installed in the sidewalk zone near the street where urban street trees are normally installed. The soil volume for the tree pit is increased and used for stormwater treatment. Treatment is increased by using a series of connected tree planting areas together in a row. The surface of the enlarged planting area may be mulch, grates, permeable pavers, or conventional pavement. The large and shared rooting space and a reliable water supply increase the growth and survival rates in this otherwise harsh planting environment.

Stormwater curb extensions (also known as street Bioretention) are installed in the road right-of way either in the sidewalk area or in the road itself. In many cases, curb extensions serve as a traffic calming or street parking control device. The basic design adaptation is to create a shallow ponding area above soil media and underdrain layers by installing a raised concrete curb adjacent to or into the street. Street runoff is diverted into the ponding area through inlets or curb cuts.

Each Urban Bioretention variant is planted with a mix of trees, shrubs, and grasses as appropriate for its size and landscaping context. **Figure UB-1** shows some typical applications for Urban Bioretention.

Figure UB-1. Typical applications for Urban Bioretention

Adjacent to building to catch roof runoff

In plaza or courtyard

Street Bioretention – curb extension linked with tree box

Extended tree pits within right-of-way

Table UB-1 describes practice performance in terms of reducing the volume associated with one inch of rainfall for Urban Bioretention. Urban Bioretention is assumed to have only one design level, under the assumption that practices will have at least 1.5 feet of soil media and an underdrain (sometimes with an impermeable liner and without an infiltration sump). It is further assumed that the extended filtration function of Urban Bioretention is limited due to limited surface area and practice sizing. Additional storage (and runoff reduction capacity) can be built into Urban Bioretention by increasing the soil media and/or underdrain layer depth, or, in rare cases, by designing an open-bottomed system that allows for infiltration.

Table UB-2 summarizes pollutant removal performance values for Urban Bioretention. This is for the purpose of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans.

Table UB-1. Urban Bioretention Design: Descriptions & Performance

Design Level	Description	Applications	Performance[1]
Level 1	Basic Design • Underdrain, often with a liner if close to building foundation or street sub-base • At least 1.5 ft. of soil media depth • No infiltration sump below underdrain pipe(s)	Ultra-urban settings, streetscapes, areas with limited space	60% volume reduction for the Design Volume of the practice[2]

[1] Performance achieved toward reducing one inch of rainfall
[2] Design Volume includes storage on the surface and within the soil media. The Design Volume can be 100% of that needed to meet the one-inch performance standard or some proportion of it when used in conjunction with other practices. See Section BR-4.1 of the Bioretention specification for sizing details.

Table UB-2. Pollutant Removal Performance Values for Level 1 and 2 Design1

Design Level	Total Suspended Solids (TSS)[2]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)[2]
Level 1	TSS = 70%	TP = 55% TN = 64%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008).
[2]These removal rates apply to practices sized for the full Treatment Volume (Tv) – in other words, sized to capture the full one-inch Tv from the drainage area. Practices that do not meet this sizing objective should multiply the removal rate by the percentage of the full Tv. For instance, if a practice is sized for ½ of the full Tv, then the TSS removal rate would be 70 x 0.5 = 35%.

UB-2. Typical Details

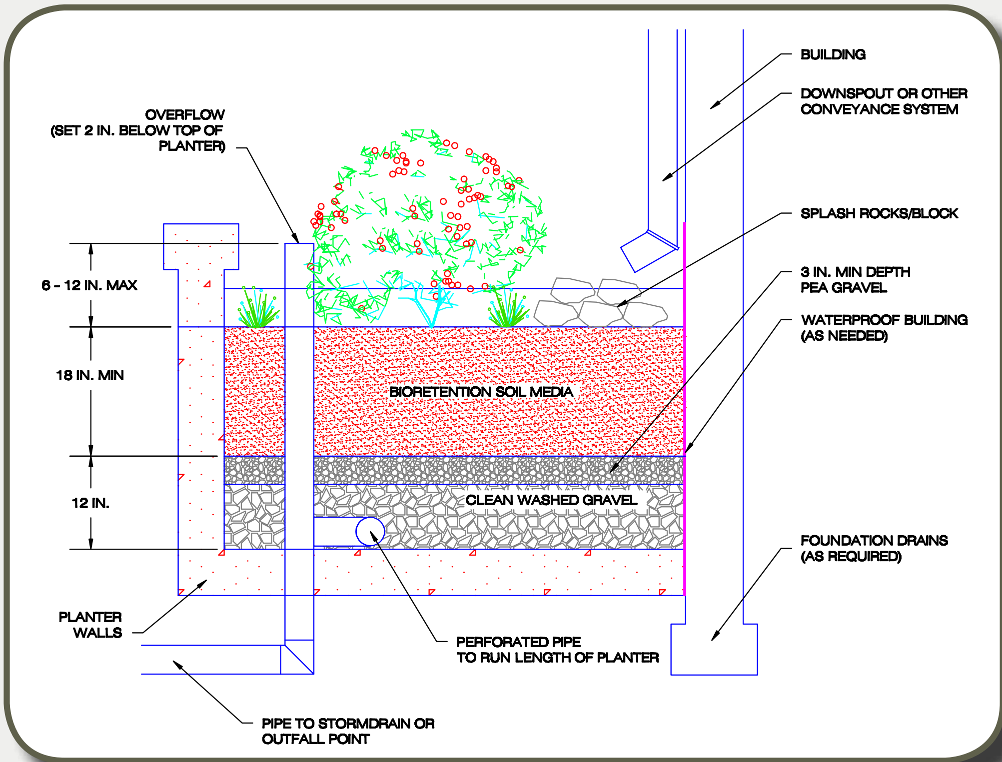

Figure UB-2. Stormwater Planter Cross-Section

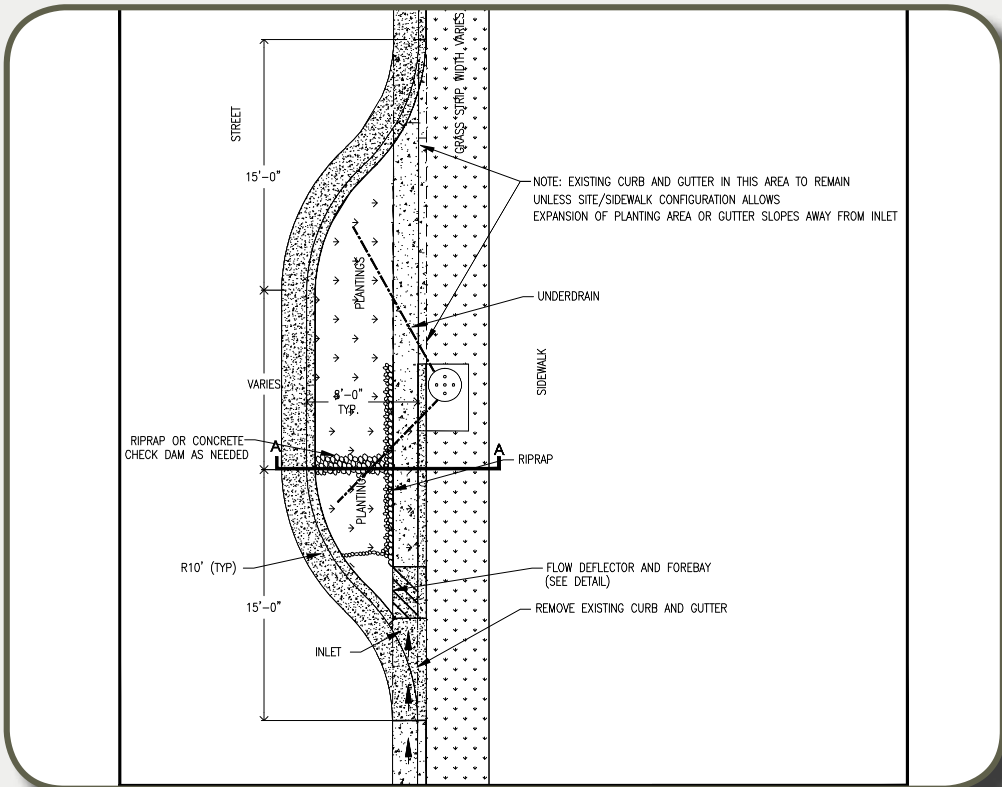

Figure UB-3. Typical plan view for stormwater curb extension tied to existing inlet structure. See Figure UB-4 for detail of cross-section A-A.

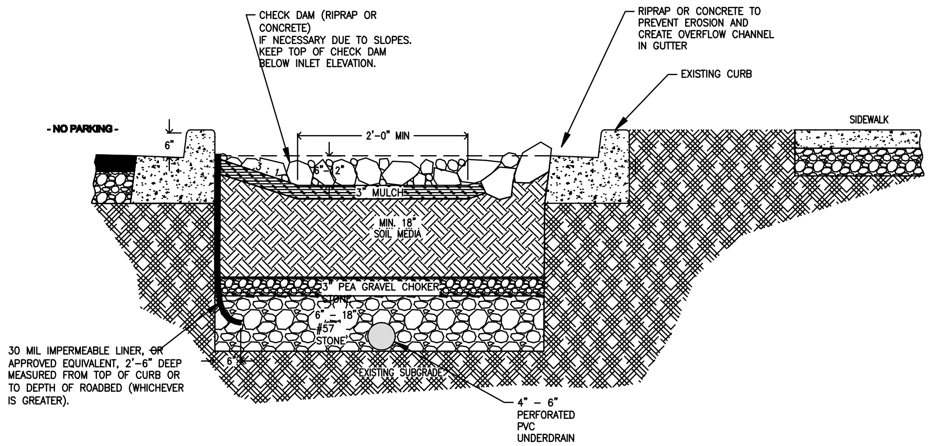

Figure UB-4. Typical cross-section for stormwater curb extension. See Figure UB-3 for location of cross-section A-A.

UB-3. Feasibility Criteria and Design Considerations

In general, Urban Bioretention has the same constraints as regular Bioretention, along with a few additional constraints as noted below:

Contributing Drainage Area. Urban Bioretention is usually limited to 2,500 square feet of drainage area to each individual unit. However, this is considered a general rule; larger drainage areas may be allowed with sufficient flow controls and other mechanisms to ensure proper function, safety, and community acceptance. The drainage areas in these urban settings are typically considered to be 100% impervious. While multiple units can be installed to maximize the treatment area in ultra-urban watersheds, Urban Bioretention is not intended to be used as treatment for large impervious areas (such as parking lots).

Available Hydraulic Head. In general, 3 to 5 feet of elevation difference is needed between the downstream storm drain invert and the inflow point of the Urban Bioretention practice. This is generally not a constraint, due to the standard depth of most storm drain systems.

Setbacks from Buildings. If an impermeable liner and an underdrain are used, no setback is needed from the building. Otherwise, the standard 10 foot down-gradient setback applies.

Proximity to Underground Utilities. Urban Bioretention practices frequently compete for space with a variety of utilities. Since they are often located parallel to the road right-of-way, care should be taken to provide utility-specific horizontal and vertical setbacks. However, conflicts with water and sewer laterals may be unavoidable, and the construction sequence must be altered, as necessary, to avoid impacts to existing service.

Overhead Wires. Designers should also check whether future tree canopy heights achieved in conjunction with Urban Bioretention practices will interfere with existing overhead telephone, cable communications and power lines.

Minimizing External Impacts. Because Urban Bioretention practices are installed in urban settings, individual units may be subject to higher public visibility, greater trash loads, pedestrian traffic, vandalism, and even vehicular loads. Designers should design these practices in ways that prevent, or at least minimize, such impacts. In addition, designers should clearly recognize the need to perform frequent landscaping maintenance to remove trash, check for clogging, and maintain vigorous vegetation. The urban landscape context may feature naturalized landscaping or a more formal design. When Urban Bioretention is used in sidewalk areas of high foot traffic, designers should not impede pedestrian movement or create a safety hazard. Designers may also install low fences, grates or other measures to prevent damage from pedestrian short-cutting across the practices.

UB-4. Inlets and Energy Dissipation

Where appropriate, the inlet(s) to Urban Bioretention systems should be stabilized using No.3 stone, splash blocks, river stone or other acceptable energy dissipation measures. The following types of inlets are recommended:

- Downspouts to stone energy dissipaters.
- Sheet flow over a depressed curb with a 3-inch drop.
- Curb cuts allowing runoff into the Bioretention area.
- Covered drains that convey flows across sidewalks from the curb or downspouts.
- Grates or trench drains that capture runoff from a sidewalk or plaza area.

UB-5. Ponding Depth

The recommended ponding depth for Urban Bioretention is 6 inches, especially in areas with high visibility, pedestrian traffic, and/or exposure to the public. In some cases where the Urban Bioretention is not as visible or architectural design considerations are used for aesthetics and public safety, a 12-inch ponding depth can be used.

UB-6. Specific Design Issues for Stormwater Planters

The two basic design variations for stormwater planters are the infiltration planter and the filter planter.

An **infiltration planter** filters rooftop runoff through soil in the planter followed by infiltration into soils below the planter. This type of design would be used rarely in cases where geotechnical testing indicates an adequate soil infiltration rate (see **Appendix B** of this Manual) and that infiltrated water will not create a problem for building foundations, road subgrades, and other infrastructure elements. The shape, length, and depth are determined by architectural and infrastructure considerations. As a general rule, the planter should be sized to treat at least 1/2-inch of runoff from the contributing rooftop area. Infiltration planters should be placed at least 10 feet away from a building to prevent possible flooding or basement seepage damage.

A **filter planter** does not allow for infiltration and is constructed with a watertight concrete shell or an impermeable liner on the bottom to prevent seepage. Since a filter planter is self-contained and does not infiltrate into the ground, it can be installed right next to a building. The minimum planter depth is 18 inches, with the shape and length determined by architectural considerations. Runoff is captured and temporarily ponded above the planter bed. Overflow pipes are installed to discharge runoff when maximum ponding depths are exceeded, to avoid water spilling over the side of the planter. In addition, an underdrain is used to carry runoff to the storm sewer system.

Additional design considerations for the filter planter include the following:

- Planters should be sized to allow captured runoff to drain out within four hours after a storm event.
- Plant materials should be capable of withstanding moist and seasonally dry conditions.
- Planting media should have an infiltration rate of at least 2 inches per hour.
- The sand and gravel on the bottom of the planter should have a minimum infiltration rate of 5 inches per hour.
- The planter can be constructed of stone, concrete, brick, wood or other durable material. If treated wood is used, care should be taken so that trace metals and creosote do not leach out of the planter.

UB-7. Specific Design Issues for Extended Tree Boxes

When designing engineered tree boxes, the following criteria should be considered:

- The bottom of the soil layer must be a minimum of 4 inches below the root ball of plants to be installed.
- Engineered tree box designs sometimes cover portions of the filter media with pervious pavers or cantilevered sidewalks. In these situations, it is important that the filter media is connected beneath the surface so that stormwater and tree roots can share this space.
- Installing an engineered tree pit grate over the filter bed media is one possible solution to prevent pedestrian traffic and trash accumulation.
- Low, wrought iron fences can help restrict pedestrian traffic across the tree pit bed and serve as a protective barrier if there is a dropoff from the pavement to the filter bed surface.
- A removable grate may be used to allow the tree to grow through it.
- Each tree needs a minimum of 400 cubic feet of root space.

UB-8. Specific Design Issues for Street Bioretention

Street Bioretention design requires more engineering than typical Bioretention. Capturing the desired drainage area (which may include both sides of a crowned roadway), conveying water into and through the facility, tying the system into the existing storm sewer, and integrating the practice with sidewalks, landscaping, and pedestrian and bike facilities all require detailed engineering analysis and design.

In addition, roadway stability can be a design issue where streetscape Bioretention practices are installed. Designers should consult design standards pertaining to roadway drainage. It may be necessary to provide an impermeable liner on the road side of the Bioretention area to keep water from saturating the road's sub-base.

UB-9. Planting and Landscaping Considerations

The degree of landscape maintenance that can be provided will determine some of the planting choices for Urban Bioretention areas. The planting cells can be formal gardens or naturalized landscapes.

In areas where less maintenance will be provided and where trash accumulation in shrubbery or herbaceous plants is a concern, consider a "turf and trees" landscaping model. Spaces for herbaceous flowering plants can be included.

Native trees or shrubs are preferred for Urban Bioretention areas, although some ornamental species may be used. As with regular Bioretention, the selected perennials, shrubs, and trees must be tolerant of salt, drought, and inundation. Additionally, tree species should be those that are known to survive well in the compacted soils and polluted air and water of an urban landscape.

UB-10. Materials Specifications for Urban Bioretention

Please consult Table BR-7 for the typical materials needed for filter media, stone, mulch and other Bioretention features. The unique components for Urban Bioretention may include the inlet control device, a concrete box or other containing shell, protective grates, and an underdrain that daylights to another stormwater practice or connects to the storm drain system.

UB-11. Construction of Urban Bioretention

The construction sequence and inspection requirements for Urban Bioretention are generally the same as micro-Bioretention practices. Consult the construction sequence and inspection guidance provided in Section BR-7.2 of the Bioretention specification. In cases where Urban Bioretention is constructed in the road or right-of-way, the construction sequence may need to be adjusted to account for traffic control, pedestrian access and utility notification.

Urban Bioretention areas should only be constructed after the drainage area to the facility is completely stabilized. The specified growth media should be placed and spread by hand with minimal compaction, in order to avoid compaction and maintain the porosity of the media. The media should be placed in 8 to 12 inch lifts with no machinery allowed directly on the media during or after construction. The media should be overfilled above the proposed surface elevation, as needed, to allow for natural settling. Lifts may be lightly watered to encourage settling. After the final lift is placed, the media should be raked (to level it), saturated, and allowed to settle for at least one week prior to installation of plant materials.

UB-12. Maintenance of Urban Bioretention

Routine operation and maintenance are essential to gain public acceptance of highly visible Urban Bioretention areas. Weeding, pruning, and trash removal should be done as needed to maintain the aesthetics necessary for community acceptance. During drought conditions, it may be necessary to water the plants, as would be necessary for any landscaped area.

For infiltration planters, inspectors should check that stormwater infiltrates properly into the soil within 24 hours after a storm. If excessive surface ponding is observed, corrective measures include inspection for soil compaction and underdrain clogging. Consult the maintenance guidance outlined in Section BR-8 of the Bioretention specification.

4.2.3 Bioretention

Supplement 4.2.3.C. Residential Rain Garden (RG)

RG-1. Residential Rain Garden

The term "Rain Garden" generally refers to a less rigorous design specification than Bioretention since the contributing drainage area is limited and the design is simplified. Rain Gardens are small, distributed practices designed to treat runoff from small areas, such as individual rooftops, driveways and other on-lot features in single-family residential developments. Inflow is typically sheet flow, or can be concentrated flow with energy dissipation, when located at downspouts.

Rain Gardens are one option for "Impervious Surface Disconnection" outlined in **Specification 4.2.2**. They can be a stand-alone practice, or used as part of a "rooftop to stream" treatment train that may include Simple Disconnection, Disconnection to a soil compost-amended filter path (see **Figure RG-2**), and Disconnection to other runoff reduction Compensatory Practices (see **Figure RG-1** for example of Disconnection to Rain Garden). **Specification 4.2.2** provides more detail on the design and runoff reduction capabilities of various treatment train approaches.

If drainage areas exceed 2,500 square feet (to each individual Rain Garden), then the main specifications for Bioretention should be used.

Figure RG-1. Example of Residential Rain Garden

Table RG-1 outlines practice performance in terms of reducing the volume associated with one inch of rainfall for Rain Gardens. Rain Gardens are assumed to have only one design level, with the requirement that practices have at least 1.5 feet of soil media and an underdrain to ensure adequate drainage within residential settings. Additional storage (and runoff reduction capacity) can be built into Rain Gardens by increasing the soil media and/or underdrain layer depth, adding an infiltration sump, or, in limited cases, by designing for infiltration by eliminating the underdrain.

Table RG-2 summarizes pollutant removal performance values for Rain Gardens. This is for the purpose of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans.

Table RG-1. Residential Rain Garden Design: Descriptions & Performance

Design Level	Description	Applications	Performance[1]
Level 1	Basic Design • At least 1.5 feet of soil media depth • Underdrain with perforated HDPE pipe or equivalent • Landscaping according to context	Mostly residential settings to treat rooftops, driveways, yards, and other areas of on-lot impervious cover	60% volume reduction for the Design Volume of the practice[2]

[1] *Performance achieved toward reducing one inch of rainfall*
[2] *Design Volume includes storage on the surface and within the soil media. The Design Volume can be 100% of that needed to meet the one-inch performance standard or some proportion of it when used in conjunction with other practices. See **Section BR-4.1** of the Bioretention specification for sizing details.*

Table RG-2. Pollutant Removal Performance Values for Level 1 and 2 Design1

Design Level	Total Suspended Solids (TSS)[2]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)[2]
Level 1	TSS = 70%	TP = 55% TN = 64%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008).
[2]These removal rates apply to practices sized for the full Treatment Volume (Tv) – in other words, sized to capture the full one-inch Tv from the drainage area. Practices that do not meet this sizing objective should multiply the removal rate by the percentage of the full Tv. For instance, if a practice is sized for ½ of the full Tv, then the TSS removal rate would be 70 x 0.5 = 35%.

RG-2. Typical Details

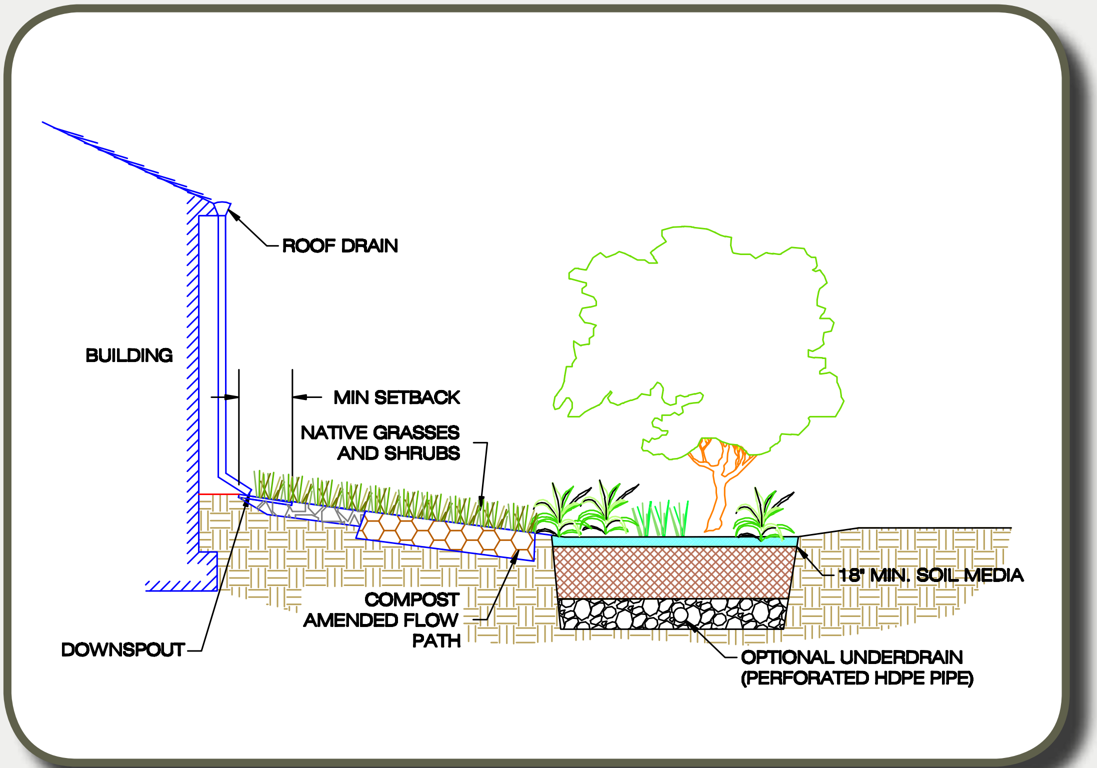

Figure RG-2. Example of Rain Garden used in conjunction with a soil compost-amended flow path (see Specification 4.2.2. Impervious Surface Disconnection).

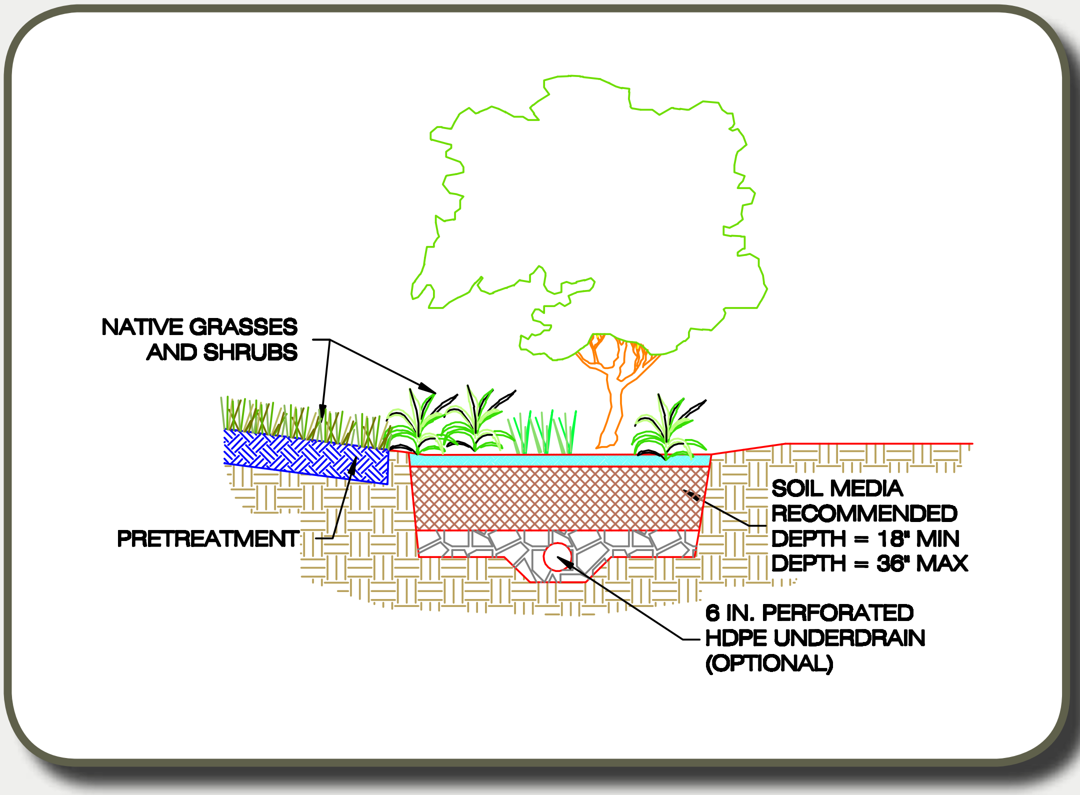

Figure RG-3. Typical detail for Rain Garden

RG-3. Design Considerations for Rain Gardens

Table RG-3 outlines specific design criteria for Rain Gardens.

Table RG-3. Design criteria for Rain Gardens.

Design Factor	Rain Garden Design
Impervious Area Treated[1]	2,500 sq. ft.
Type of Inflow	Sheet flow; Concentrated flow with level spreader or energy dissipater
Minimum Soil Infiltration Rate	0.5 in./hr. (or use underdrain)
Observation Well/Cleanout Pipes	No
Pretreatment	Energy dissipater, grass filter (e.g., flow through several feet of yard before flow reaches Rain Garden)

Design Factor	Rain Garden Design
Ponding Depth	6-in. in most cases
Underdrain	Yes, in most cases.[1] Underdrains to daylight in yard, road ditch, or storm sewer (e.g., in the street)
Impermeable Liner	For hotspot or karst designs, or adjacent to foundations.
Gravel Layer	12 in.
Minimum Filter Media Depth	18 in.
Media Source	Can be mixed on-site
Head Required	Nominal, 1 to 3 ft.
Sizing	See **Section BR-4.1 in main Bioretention specification**
Landscaping	**See Section BR-4.17 in the main Bioretention specification.** Simple landscape plans are best, and can include turf, herbaceous layers, shrubs, and trees
Required Soil Borings	One, only when an underdrain is not used
Building Setbacks	5 ft. down-gradient, 25 ft. up-gradient (or use an impermeable liner)

[1] *Refer* ***Section BR-4.10 in main Bioretention specification***

RG-4. Conveyance for Rain Gardens

Rain Gardens should include provisions to bypass flows around the practice when the rain event exceeds the Design Volume. The adjacent pervious areas should be designed to safely convey design and large storm events away from the practice and to a receiving area without causing erosion. Since the rooftop drainage systems (roof leaders) typically limit the flow, there are generally no detailed conveyance criteria related to a design storm or peak flow rate.

RG-5. Construction Considerations for Rain Gardens

Sequencing of construction for Rain Gardens is critical, especially for on-lot practices. The Rain Garden should not be installed until the drainage area is stabilized with vegetation. Early installation will likely result in practice failure. This can be tricky because it involves close coordination between contractors (building the road), builders, and subcontractors. See the main Bioretention specification for more detail on construction sequence.

RG-6. Maintenance Considerations for Rain Gardens

Rain Gardens require regular mowing and/or landscape maintenance to perform effectively. It is recommended that Rain Gardens be located in an expanded right-of-way or stormwater easement so that they can be easily accessed for inspection, maintenance, or in the event that they fail to drain properly.

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4.2.4. Permeable Pavement (PP)

PP-1. Introduction

Permeable Pavements are alternative paving surfaces that capture and temporarily store the Target Treatment Volume (Tv) by filtering runoff through voids in the pavement surface into an underlying stone reservoir. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially infiltrate into the soil.

Permeable Pavements can be used to:

- Manage the first one inch of rainfall on-site using an Infiltration Design with no underdrain (see **Table PP-1**, Level 2 design)
- Manage the first one inch of rainfall on-site using an Infiltration Sump Design with an underdrain and an infiltration sump (see **Table PP-1**, Level 2 design)
- Partially manage the first one inch of rainfall on-site using a Basic Design with an underdrain (see **Table PP-1**, Level 1 design)
- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs; see **Table PP-2**).
- Meet partial or full storage requirements for local stormwater detention standards
- Retrofit existing developed areas, especially highly impervious areas

Permeable Pavements can be blended into the urban environment by replacing almost any paved surface. Designers often limit the application of Permeable Pavement to parking stalls and lower traffic areas such as emergency access roads or non-travel lanes of parking lots. However, new materials and construction techniques have made Permeable Pavements applicable to most applications. Examples illustrated in the photos above include parking lot Concrete Grid Pavers (left) and a Porous Asphalt parking lot (right). The photo on the right illustrates the porosity of the pavement passing water through the pavement section without any runoff.

For the purposes of this section, "Permeable Pavement" refers to **Pervious Concrete, Porous Asphalt, Concrete Grid Pavers, Permeable Interlocking Concrete Pavers** and other products and configurations that are designed for the same purpose (plastic, dirt or grass filled pavers, interlocking pavers, etc.).

Figure PP-1 further illustrates typical Permeable Pavement materials and applications. **Figures PP-2 and PP-3** are schematics of a typical Permeable Pavement sections and profiles. **Tables PP-1 and PP-2** describe two levels of Permeable Pavement design and associated volume reduction and pollutant removal performance rates. **Table PP-3** is a design checklist to help guide the design process for Permeable Pavement practices.

PP-1.1 Planning This Practice

Figure PP-1. Typical Permeable Pavement Materials

Pervious Concrete

Porous Asphalt

Concrete Grid Pavers

Permeable Interlocking Concrete Pavers

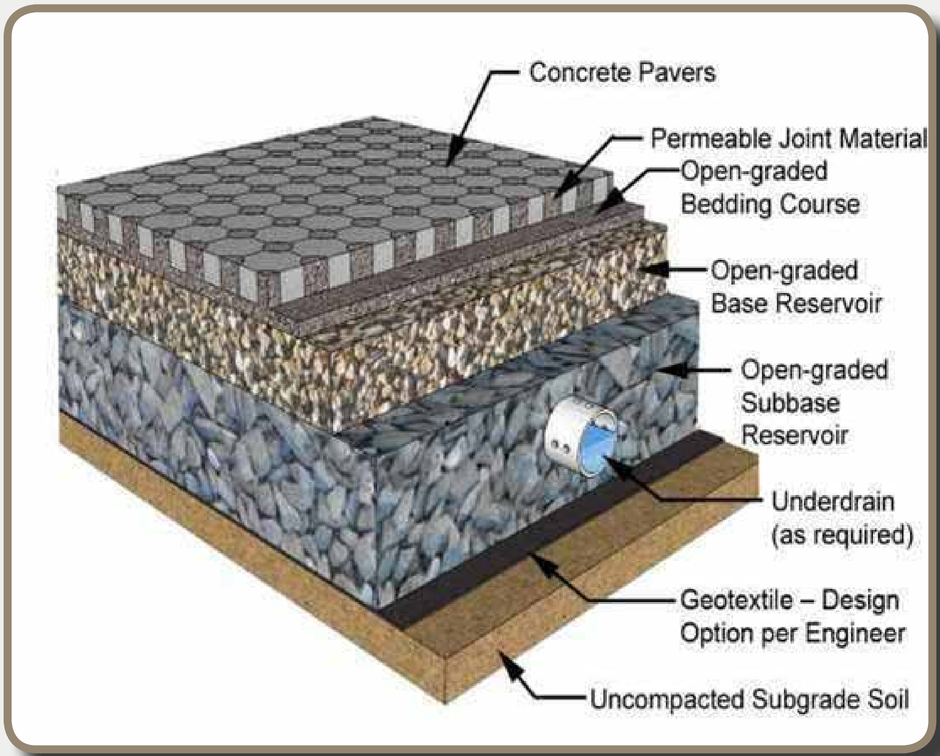
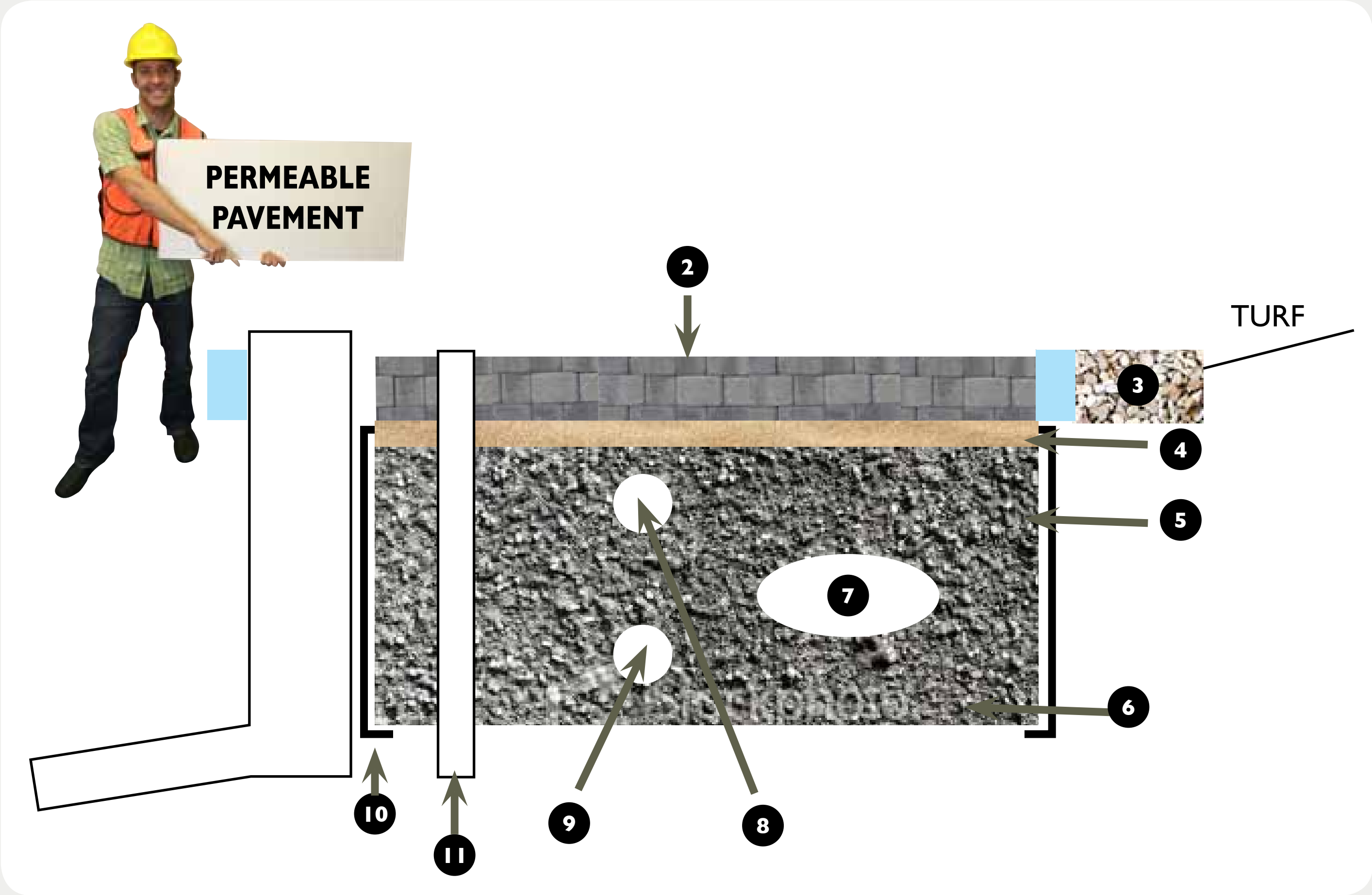


Figure PP-2. Schematic Profile for Typical Permeable Pavement Section (Source: David Smith, ICPI).

Figure PP-3. Schematic for Typical Permeable Pavement



1. **Overflow/storm drain structure** – Section PP-4.4
2. **Pavement type** – Sections PP-1.1 & PP-4
3. **Pretreatment (if needed)** – Section PP-4.5
4. **Bedding layer (as per manufacturer)**
5. **Reservoir layer** – Sections PP-4.1, PP-4.2, PP-4.6
6. **Infiltration sump (reservoir below underdrain)** – Sections PP-4.1 & PP-4.6
7. **Additional storage for larger storms (optional)** – Section PP-4.3
8. **Overdrain (optional)** – Section PP-4.4
9. **Underdrain (Level 1 standard design & Level 2 infiltration sump design)** – Section PP-4.7
10. **Filter fabric (sides only)** – Section PP-4.9
11. **Observation well** – Section PP-4.8

PP-1.2 Permeable Pavement Design Options & Performance

Table PP-1 describes the Level 1 and Level 2 design options for Permeable Pavement and the practice performance in terms of reducing the volume associated with one inch of rainfall on the site. **Table PP-2** summarizes pollutant removal performance values for Level 1 and Level 2 designs. This is for the purpose of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans.

Table PP-1. Permeable Pavement Design Levels: Descriptions & Performance

Design Level	**Description**	**Applications**	**Performance**[1]
Level 1	Basic Design - • Underdrain design • Depth of reservoir layer (above underdrain) from Equation PP-1. • No infiltration sump below underdrain pipe(s)	• Sites with poor soils or constructed on fill material; • Constraints such as high bedrock or water table OR confirmed karst, stormwater hotspot, or other applications that require an impermeable liner.	45% volume reduction for the Design Volume of the practice[2]
Level 2	Infiltration Design: • No underdrain • Depth of reservoir layer from Equation PP-1. • Water infiltrates into the underlying soil within 48 hours	• Sites with permeable soils; confirmed infiltration rates ≥ 0.5 in./hr	100% volume reduction for the Design Volume of the practice[2]
	Infiltration Sump Design: • Underdrain • Depth of reservoir layer (above underdrain) from Equation PP-1. • Sump below underdrain sized to drain within 48 hours (based on confirmed infiltration rate)	• Sites with marginal soils • Sites with permeable soils where an underdrain is preferred	• 100% volume reduction for the part of the Design Volume contained in the sump[3]; • 45% volume reduction for the part of the Design Volume in the reservoir layer (above and including the underdrain)[2]

[1] *Performance achieved toward reducing one inch of rainfall*

[2] *Design Volume includes storage within the stone reservoir below the pavement surface, including the volume of the infiltration sump, if used. The Design Volume can be 100% of that needed to meet the 1-inch performance standard for the contributing drainage area ("Target Treatment Volume") or some proportion of it when used in conjunction with other practices. See* **Section PP-4.1** *for sizing details.*

[3] *Sump depth and volume based on ability to fully drain within 48 hours based on confirmed infiltration rate. See Section PP-4 for design and sizing details.*

Table PP-2. Total Pollutant Load Reduction Performance Values for Level 1 and 2 Design

Design Level	Total Suspended Solids (TSS)[1]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN) [1]
1	TSS = 81%	TP = 59% TN = 59%
2	TSS = 91%	TP = 81% TN = 81%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008).

PP-1.3. Permeable Pavement Design Checklist

Table PP-3. Permeable Pavement Design Checklist

CHECKLIST

This checklist will help the designer through the necessary design steps for Permeable Pavement.

- ☐ Check feasibility for site – **Section PP-3**
- ☐ Determine applicability of Level 2 Infiltration Design or Infiltration Sump Design, or Level 1 Basic Design based on soils/geotechnical investigation; **Table PP-1**
- ☐ Complete Site Design Spreadsheet to determine the Target Treatment Volume (Tv) plan and confirm required Permeable Pavement Stone Reservoir Sizing, and any additional practices needed, and overall site compliance – Site Compliance Spreadsheet & **Chapter 3** of Manual
- ☐ Check Permeable Pavement sizing guidance and make sure there is an adequate footprint (often split into multiple areas) on the site for Permeable Pavement area(s) – **Sections PP-4.1 & PP-4.2**
- ☐ Check design adaptation appropriate to the site – **Section PP-6**
- ☐ Design Permeable Pavement in accordance with design criteria and typical details – **Sections PP-2 & PP-4**
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence and notes

PP-2. Typical Details

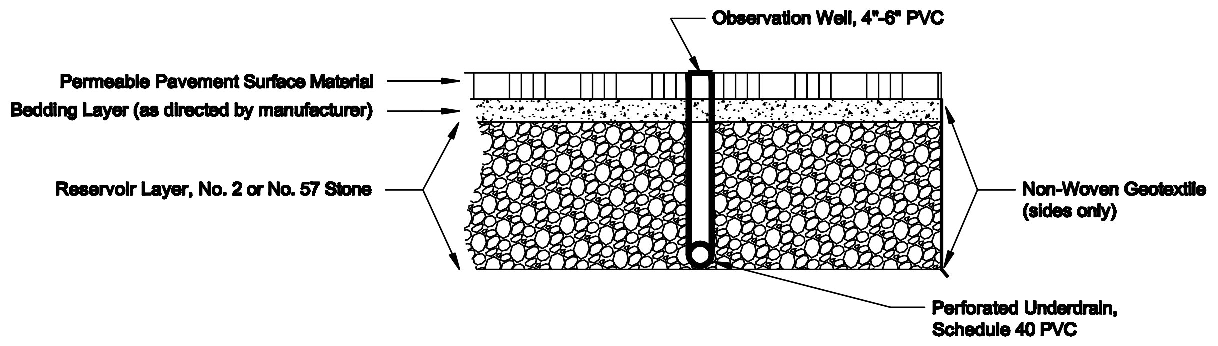


Figure PP-4. Cross Section of a Basic Level 1 Permeable Pavement Design

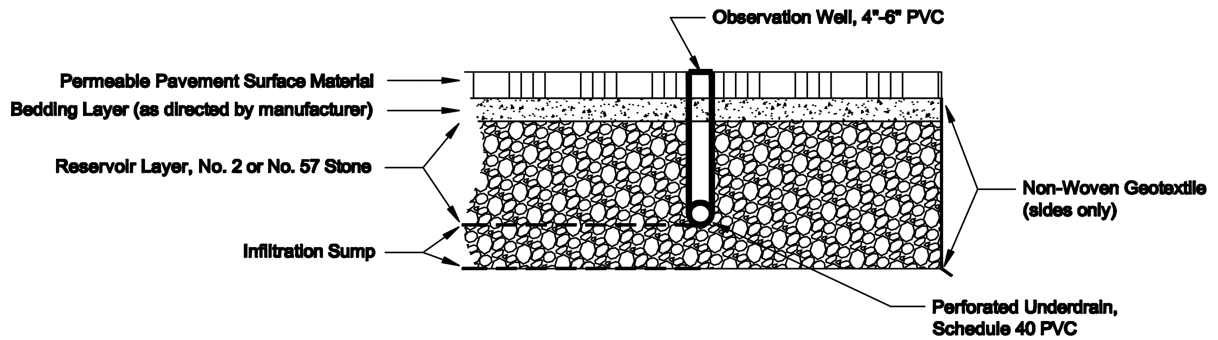


Figure PP-5. Cross Section of Level 2 Permeable Pavement Design with Infiltration Sump

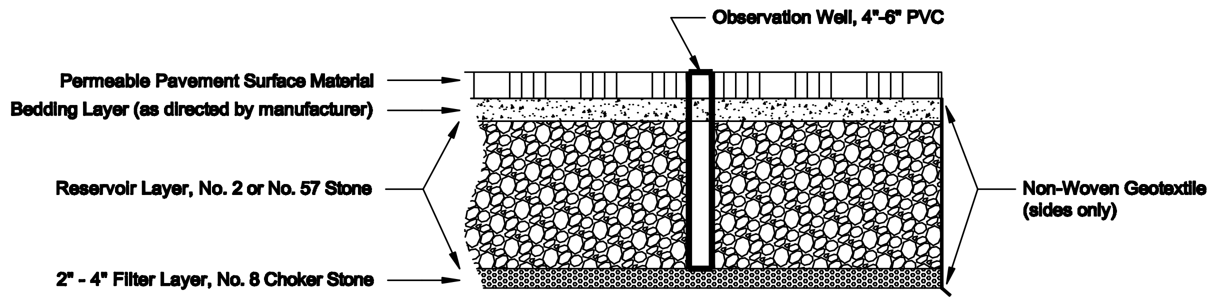


Figure PP-6. Cross Section of Level 2 Permeable Pavement Infiltration Design

4.2.4. Permeable Pavement (PP)

PP-3. Feasibility Criteria and Design Considerations

Since Permeable Pavement has a very high runoff reduction capability, it should be considered as an alternative to conventional pavement on any design. The Basic Design (Level 1) can be applied at most development sites, while the Infiltration Design and Infiltration Sump Design (Level 2) are subject to the same feasibility constraints as Infiltration practices.

Key constraints for Permeable Pavement include the following:

Available Space. A prime advantage of Permeable Pavement is that it does not normally require additional space at a new development or redevelopment site, which can be important for tight sites or areas where land value is high.

Site Topography. Steep pavement surface slopes can reduce the stormwater storage capability of Permeable Pavement and may cause shifting of the pavement surface and base materials. Further, long runs of pavement on a slope will allow runoff to migrate downslope through the reservoir and pool at the lower end of the pavement. Designers should consider using a terraced design for Permeable Pavement in sloped areas, especially when the finished parking grade will be 3 percent or greater.

Pavement Section Bottom Slope. The bottom slope of a Permeable Pavement Infiltration or Infiltration Sump installations should be as flat as possible (i.e., 0% longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater. On sloped sites, internal check dams or berms can be incorporated into the subsurface to encourage infiltration.

If an underdrain design is used, low-grade longitudinal slopes on the bottom and the underdrain (i.e., 0.5%) are required to ensure the system drains, but the designer must account for this grade when establishing the stone reservoir minimum depth. On especially long runs, this may result in the reservoir depth being deeper at the lower end in order to create the required storage volume.

External Drainage Area. The area of pavement draining onto ("run-on") a Permeable Pavement section should be limited to two times the area of Permeable Pavement. The external drainage area should be as close to 100% impervious as possible. Both of these constraints are the result of numerous observations of Permeable Pavements being overloaded with sediment and grit (pavement erosion) increasing the required frequency of maintenance.

Limit the Size of the External Drainage Area for Long-Term Performance & Maintenance

The external drainage area contributing "run-on" to a Permeable Pavement section is limited to two times the area of the Permeable Pavement. For example: a 1 acre section of Permeable Pavement can have up to 2 adjacent acres sheet flowing to the permeable section. Keeping this "run-on" to a minimum, and limiting it to impervious cover has been demonstrated to maximize the performance life and minimize the frequency of maintenance of Permeable Pavement.

Available Hydraulic Head. The elevation difference needed for Permeable Pavement to function properly is generally nominal, although 2 to 4 feet of head from the pavement surface to the underdrain outlet is optimal (this value may vary based on several design factors such as whether an underdrain or an upturned elbow is used).

Water Table. A high groundwater table may cause runoff to pond at the bottom of the Permeable Pavement system. Therefore, a minimum vertical distance of 2 feet must be provided between the bottom of the Permeable Pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table.

Soils. Soil conditions do not typically constrain the use of Permeable Pavement, although they do determine whether an underdrain is needed. Underdrains are required if the measured permeability of the underlying soils is less than 0.5 in/hr. Designers may choose to incorporate an infiltration sump below the underdrain where underlying soils are marginal (in the range of 0.1 to 0.5 in/hr). In either case, designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix B. Low permeability soils will require an underdrain.

In fill soil locations, geotechnical investigations are required to determine if the use of an impermeable liner and/or underdrain are necessary or if the use of an infiltration sump (see Section PP-4 for Design Criteria) is permissible.

Use of Permeable Pavement on Fill Section

In areas of significant fill, soil slips can result from infiltrating water, including use of an infiltration sump. It is preferable to use this type of design in cut sections. Geotechnical investigations are required if any design that infiltrates water will be used in a fill section. Impermeable liners and underdrains (without a sump) may be necessary, based on the outcome of the investigation (see Section PP-4.10).

Hotspot Land Uses. Permeable Pavements should not be used to treat hotspot runoff. However, Permeable Pavement can still be used to treat "non-hotspot" parts of the site; for instance, employee or visitor parking while vehicular maintenance or other hotspot areas would be treated by a more appropriate practice.

For a list of potential stormwater hotspots, please consult Chapter 5 of the Manual.

High Traffic or High Pollutant Loading Conditions. Permeable Pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail without frequent and intensive maintenance. Sites with a lot of pervious area (e.g., newly established turf and landscaping) can be considered high loading sites and the pervious areas should be diverted away from the Permeable Pavement area if possible. If directing runoff from new pervious areas to the Permeable Pavement is unavoidable, aggressive pretreatment measures should be employed.

High Speed Roads. Permeable Pavement should not be used for high speed roads, although it has been successfully applied for low speed residential streets, parking lanes and roadway shoulders.

Floodplains. Permeable Pavement should be constructed outside the limits of the 100-year floodplain, unless a waiver is obtained from the local authority.

Non-Stormwater Discharge. Permeable Pavement should not receive non-stormwater discharges such as irrigation runoff, air-conditioning condensation discharge, chlorinated wash-water or other such non-stormwater flows.

Setbacks. To avoid the risk of seepage, Permeable Pavement practices should not be hydraulically connected to structure foundations. Setbacks to structures vary based on the size of the Permeable Pavement installation:

- 250 to 1,000 square feet of Permeable Pavement = 5 feet if down-gradient from building; 25 feet* if up-gradient.
- 1,000 to 10,000 square feet of Permeable Pavement = 10 feet if down-gradient from building; 50 feet* if up-gradient.
- More than 10,000 square feet of Permeable Pavement = 25 feet if down-gradient from building; 100 feet* if up-gradient.

* In some cases, the use of an impermeable liner along the sides of the Permeable Pavement practice (extending from the surface to the bottom of the reservoir layer) may be used as an added precaution against seepage, and the setback requirements can be relaxed.

At a minimum, Permeable Pavement Infiltration Design or Infiltration Sump Design applications should be located a minimum horizontal distance of 100 feet from any water supply well and at least 5 feet down-gradient from dry or wet utility lines. These setbacks are general guidelines and may be reduced by the local plan approving authority if precautions are taken.

Proximity to Utilities. Interference with underground utilities should be avoided whenever possible, particularly water and sewer lines. Under no circumstances should utility lines be run through the stone reservoir. Approval from the applicable utility company or agency is required if utility lines will run below or immediately adjacent to a Permeable Pavement installation.

Conflicts with water and sewer laterals (e.g., house connections) on residential driveway applications may be unavoidable, and the construction sequence must be altered, as necessary, to avoid impacts to existing service.

Community Factors. Permeable Pavement can be designed as a safe and aesthetically pleasing practice. Creative mosaic paver designs can be utilized in highly visible pedestrian residential or commercial areas.

Underground Injection Permits. Permeable Pavement is not considered to be Class V wells subject to permits under the Underground Injection Control (UIC) Program (U.S. EPA, 2008). However, in certain cases the designer should confer with West Virginia Department of Environmental Protection (WVDEP) about the possible applicability of a UIC permit. These cases would include Infiltration Designs (or Infiltration Sump Designs) in close proximity to sensitive groundwater areas (e.g., aquifers overlain with thin, porous soils), or designs with a subsurface fluid distribution system (e.g., underdrains that do not discharge to the surface or the storm drain system).

PP-4. Design Criteria

The design of Permeable Pavement includes the selection of the pavement type: **Pervious Concrete, Porous Asphalt, Concrete Grid Pavers, Permeable Interlocking Concrete Pavers,** and other products that are designed to support varying amounts of vehicle or pedestrian traffic. The type of pavement should be selected based on a review of the pavement specifications and properties, and the proposed site conditions, and designed according to the product manufacturer's recommendations.

The critical components of the design related to stormwater quality and runoff volume reduction is the internal or subsurface geometry, including the stone reservoir layer and the designation of an underdrain and/or infiltration sump based on the soil conditions under the proposed pavement (Hunt and Collins, 2008).

The thickness of the stone reservoir layer is determined by both a structural and hydraulic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. The Permeable Pavement structural design is discussed in **Section PP-4.2**, and is critical to the design since it may impact the ability to use an Infiltration Design.

Consider Structural Load Capacity as Part of the Design Process

An additional pavement design element is the structural load capacity of the pavement section. **Section PP-4.2** provides a brief discussion of this design element as it may relate to the subgrade preparation or the selection of pavement material. Designers should investigate this design parameter before applying an Infiltration Design.

PP-4.1. Permeable Pavement Sizing for Water Quality & Volume Reduction

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a best management practice (BMP) plan:

Target Treatment Volume (Tv) = Volume associated with managing 1" of rainfall based on the size and land cover of the contributing drainage area (CDA), as determined by the Design Compliance Spreadsheet. Any given BMP may treat the full Tv or only part of it if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on storage within different layers as prescribed in the BMP specification. For Permeable Pavement, Dv will equal Tv if the CDA is only the pavement surface itself and any external drainage area. However, if Permeable Pavement is used in conjunction with downstream runoff reduction practices, the Dv of the Permeable Pavement can be a subset of the overall Tv. In such cases, the sum of the Dvs in the Permeable Pavement plus those of the other practices in the treatment train should equal the total drainage area Tv.

See **Chapter 3** for more information on the runoff reduction design methodology.

Permeable Pavement design for runoff reduction and water quality consists of sizing the stone reservoir for one of the following design configurations:

1. Basic Design (Level 1) where the depth of stone reservoir above and including the underdrain is sized to store the Dv; **the runoff reduction credit is 45% of the Dv.**
2. Infiltration Sump Design (Level 2) where the combined depth of stone reservoir above and including the underdrain and the infiltration sump are sized to store the Dv; **the runoff reduction credit is 100% of the portion of the Dv stored in the sump, and 45% of the portion of the Dv stored above the sump**; or
3. Infiltration Design (Level 2) where the depth of stone reservoir is sized to store the Dv; **the runoff reduction credit is 100% of the Dv** provided.

The Level 1 design is intended for those sites where the infiltration rate of the soil is below the minimum design rate of 0.5"/hr. The Level 2 Infiltration Sump Design is intended for those applications where the soils may be marginal, the pavement structural design will result in a diminished soil infiltration rate, or the pavement section design requires that the stone reservoir be dewatered, but does allow for the full infiltration design (no underdrain). The Infiltration Sump Design provides a 100% runoff reduction credit for the volume of the infiltration sump. The Level 2 Infiltration Design is for applications where the existing soils are adequate and the construction of the Permeable Pavement section is such that the underlying soils can be utilized for infiltration.

Underdrains Can Flow to Downgradient Practices, Such as Infiltration

Some designers are reluctant to design a Permeable Pavement section without an underdrain since the structural requirements will require some compaction of the underlying soils (refer to Section PP-4.2), potentially limiting or even eliminating the infiltrative capacity of the soils. Since this will potentially lead to pavement failure, some designers have elected to convey the runoff from the underdrain to an adjacent infiltration trench (stone reservoir out from under the pavement section). The infiltration trench can be designed to accept surface runoff from the perimeter impervious pavement, as well as subsurface inflow from the underdrain.

The sizing of the stone reservoir consists of establishing the depth of the stone to store the Dv. An additional design step is to consider the storage or conveyance of larger storms (discussed in **Sections PP-4.3 and PP-4.4**). Both of these volume requirements can be established through a storage indication routing program using the underdrain or the infiltration rate to accurately determine the required reservoir depth. Or the designer may use **Equation PP-1** to approximate the depth of the reservoir layer.

Level 1 Underdrain and Infiltration Designs

Equation PP-1 can be used to design the depth of the stone reservoir layer above and including the underdrain for the Basic Design, and the entire stone reservoir layer for the Infiltration Design.

Equation PP-1

$$d_{stone} = \frac{(P \times A_I \times Rv_I) + (P \times A_P)}{\eta_r \times A_P}$$

d_{stone} = Depth of the stone reservoir layer (ft)
P = Rainfall depth (1") for the design Treatment Volume = 0.083 ft.
A_I = Contributing impervious drainage area (ft^2)
Rv_I = Volumetric Runoff Coefficient for impervious cover = 0.95
A_P = Area of permeable pavement (ft^2)
η_r = porosity of reservoir layer (0.4)

Equation PP-1 makes the following design assumptions:

- The contributing drainage area (AI) is entirely impervious. Pervious areas should be diverted to alternate drainage systems. If this is not possible, the pervious areas should be directed to pretreatment as described in **Section PP-4.5** prior to draining to the Permeable Pavement.
- The ratio of the area of impervious pavement contributing runoff to the Permeable Pavement area shall be no greater than 2;
- The surface area of the Permeable Pavement is equal to that of the stone reservoir.
- The porosity (ηr) for No. 57 stone = 0.4. Designers should verify the acceptance of a different value if an alternate stone designation is used.
- The pavement section surface and reservoir bottom are level. Since this is not likely, the designer should ensure that the depth of the stone reservoir from **Equation PP-1** is the minimum dimension at the upper end of the pavement and the depth gradually increases along the slope of the section. The designer can incorporate baffles into the stone reservoir design if needed.

Minimum Depth of Stone Reservoir

In the absence of a minimum design factor based on the structural design of the pavement, the depth of the stone reservoir layer (dstone) should be a minimum of six (6) inches above the underdrain or the choker stone layer on Infiltration Designs.

Level 2 Infiltration Sump Design

The Infiltration Sump Design includes the use of the infiltration sump beneath the underdrain. The intent is to allow for infiltration into the underlying soils even if the soil infiltration rate is marginal (< 0.5''/hr). The depth of the sump is therefore sized according to confirmed design infiltration rate of the underlying soils and their ability to drain the sump within 48 hours using **Equation PP-2**.

Equation PP-2

$$d_{IS} = \frac{{}^{1}/_{2}\, i \times t_d}{12}$$

Where:

d_{IS} = Maximum depth of the stone infiltration sump (ft)
i = field-verified infiltration rate for the sub-grade soils (inches/hr)
t_d = design drain time of sump = 48 hours

Table PP-4. Maximum Depth of Infiltration Sump corresponding to Infiltration Rates

Field Verified Infiltration rate (i) (in./hr.)	Design Drawdown Time (t_d), (hrs.)	Depth of Infiltration Sump[1] (d_{IS}) (in.)
0.5[2]	48	12
0.25	48	6
0.1	48	2.4[3]

[1]Depth of sump is the total depth with gravel. Effective depth of water storage = dIS x ☐ (0.4)
[2]Field verified infiltration rate of 0.5 in./hr. allows Infiltration Design.
[3] Due to construction tolerances and the practical measure of gravel placement, designers should assume a minimum dIS of 4 in.

Once the depth of the infiltration sump is determined, the corresponding depth of the stone reservoir above the sump (Reservoir Layer in **Figure PP-5**) can be calculated by subtracting the depth of the infiltration sump (Infiltration Sump in **Figure PP-5**) from the total required depth of stone calculated with **Equation PP-1** as provided in **Equation PP-3**:

Equation PP-3

$$d_{res} = d_{stone} - d_{IS}$$

Where:

d_{res} = Depth of the stone reservoir above the sump (ft) (Reservoir Layer in **Figure 4**)
d_{stone} = Depth of the stone reservoir layer from **Equation 4.1**
d_{IS} = Depth of the stone infiltration sump (ft) from **Equation 4.2** (Infiltration Sump in **Figure 4**)

PP-4.2. Structural Design

If Permeable Pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific design recommendations. In general, traffic load is supported by the thickness of the Permeable Pavement and reservoir layer along with the underlying soil strength. On most new development and redevelopment sites, the structural support requirements will require a greater depth of stone reservoir than the design Tv.

The structural design of Permeable Pavements generally involves the consideration of four main site elements:

- Total traffic;
- In-situ soil strength;
- Environmental elements; and
- Surface materials, bedding and reservoir layer design.

The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layers. Designers should note that if the underlying soils have a low California Bearing Ratio (i.e, less than 4%), they may need to be compacted to at least 95% of the Standard Proctor Density, which generally limits their use for infiltration. Other options include the use of geotextiles or geogrids placed under the stone reservoir or infiltration sump to better distribute the traffic loads to an uncompacted fill.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- Guide for Design of Pavement Structures (AASHTO, 1993); and,
- Supplement to the Guide for Design of Pavement Structures (AASHTO, 1998).

Permeable Pavement Structural Design – The structural design process for supporting vehicles varies according to the type of pavement selected. ASTM test methods for characterizing compressive or flexural strengths of pervious concrete are currently being developed. These tests are needed to model fatigue under loads. As an interim step, fatigue equations published by the American Concrete Pavement Association (ACPA 2010) assume such inputs to be comparable in nature (but not magnitude) to those used for conventional concrete pavements. The ACPA design method should be consulted for further information.

General guidelines for pervious concrete surface thickness are published by the National Ready Mix Concrete Association and the Portland Cement Association (Leming 2007).

Porous asphalt (Hansen 2008) and permeable interlocking pavements (Smith 2010) use flexible pavement design methods adopted from the 1993 AASHTO ***Guide for Design of Pavement Structures*** (AASHTO 1993). In addition, manufacturer's specific recommendations should be consulted.

Concrete grids only see intermittent traffic and generally only require a minimum 8 inch thick compacted, dense-graded base. The minimum open-graded base and subbase thicknesses under permeable interlocking concrete grid pavement can generally be used for water storage

There has been little research or full-scale testing of the structural behavior of open-graded bases used under permeable pavements to better characterize the relationships between loads and deformation. Therefore, conservative values (i.e., AASHTO layer coefficients) should be assumed for open-graded base and subbase aggregates in permeable pavement design.

Regardless of type of permeable pavement, structural design methods consider the following in determining surface and base thicknesses to support vehicular traffic:

- Pavement life and total anticipated traffic loads expressed as 18,000 lb equivalent single axle loads or ESALs (This method of assessing loads accounts for the additional pavement wear caused by trucks.)
- Soil strength expressed as the soaked California Bearing Ratio (CBR), R-value or resilient modulus (Mr)
- Strength of the surfacing, base and subbase materials
- Environmental factors including freezing climates and extended saturation of the soil subgrade

Soil stability under traffic should be carefully reviewed for each application by a qualified geotechnical or civil engineer and the lowest anticipated soil strength or stiffness values used for design. Structural design for vehicular applications assumes the following:

- Minimum soil CBR of 4% (96-hour soaked per ASTM D 1883 or AASHTO T 193); or
- Minimum R-value = 9 per ASTM D 2844 or AASHTO T-190; or
- Minimum Mr of 6,500 psi (45 MPa) per AASHTO T-307

Soil compaction required to achieve this criteria will reduce the infiltration rate of the soil. Therefore, the permeability or infiltration rate of soil should be assessed at the density required to achieve one of these values.

PP-4.3. Permeable Pavement Sizing for Larger Storms (Local Detention Criteria)

Permeable Pavement can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various combinations of storage within the stone aggregate layer, expected infiltration, additional storage in the form of chambers or perforated storage pipes in the upper elevations of the stone reservoir, and any outlet structures used as part of the design. Routing calculations with a stage-storage-discharge relationship can be used to provide a more accurate representation of the Permeable Pavement's influence on the required design storms (2-year, 10-year, etc.).

It should be noted that all site designs should include provisions for safe conveyance of larger flows, either contained within properly sized pipe or channel systems or as overland flood routing to a receiving waterbody, so as to minimize public safety risks and property damage. While some large storm detention credit can be realized by oversizing runoff reduction practices such as Permeable Pavement (which may reduce the size or footprint of downstream detention structures), the downstream drainage system and flood routing should be designed conservatively and be based on the expected peak rate of discharge without any downsizing credited to runoff reduction.

PP-4.4. Conveyance and Overflow

Permeable Pavement designs should include methods to convey larger storms (e.g., 2-yr, 10-yr) to the storm drain system or receiving water body. The following is a list of methods that can be used to accomplish this:

- Place an overdrain, a perforated pipe laid horizontally near the top of the reservoir layer, to pass excess flows after water has filled the base.
- Increase the thickness of the top of the reservoir layer by as much as 6 inches to increase storage (i.e., create freeboard). The design computations used to size the reservoir layer do not include freeboard.
- Create underground detention within the reservoir layer of the Permeable Pavement system. Reservoir storage may be augmented by corrugated metal pipes, plastic or concrete arch structures, etc.
- Route excess flows to another detention or conveyance system that is designed for the management or detention of large storms.
- Set the storm drain inlets flush with the elevation of the Permeable Pavement surface to effectively convey excess stormwater runoff past the system. The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

PP-4.5. Pretreatment

The best pretreatment technique for Permeable Pavement is to limit the CDA to pavement. Traffic will carry particulate pollutants onto the pavement section, and the pavement itself is subject to wear and over time will create its own particulate load. However, the most common cause of pavement clogging is the presence of landscaped or turf areas in the CDA. Turf areas will take 1 to 2 growing seasons to fully vegetate and lock soil in place. Large intense rain events will mobilize sediment onto the pavement.

Landscaped areas and lawn cutting operations will potentially mobilize high concentrations of organic particulates that can contribute to pavement clogging as well. Additional pretreatment may be appropriate if the pavement receives run-on from these types of areas. For example, a gravel or sod filter strip can be placed adjacent to pervious (landscaped) areas to trap coarse sediment particles before they reach the pavement surface.

PP-4.6. Permeable Pavement Design Elements

The three major components of Permeable Pavement section are the pavement itself, the reservoir layer, the infiltration sump, and the filter layer.

Permeable Pavement

Several different brands of pavement materials are available in each of the categories of Permeable Pavements: Pervious Concrete, Porous Asphalt, Concrete Grid Pavers, and Permeable Interlocking Concrete Pavers. Designers should periodically request updates from the different manufacturers as these materials have undergone many manufacturing and installation improvements over the years. Further, manufacturers will typically provide detailed design assistance in order to optimize the performance of the product.

Reservoir layer

The reservoir layer consists of the stone underneath the pavement section and above the bottom filter layer and underlying soils.

- The stone reservoir below the Permeable Pavement surface should be composed of clean, washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading.
- The stone reservoir may consist of clean washed No. 57 stone, although No. 2 stone is preferred because it provides additional structural stability.
- The bottom of the reservoir layer should be completely flat when using an Infiltration Design so that runoff will be able to infiltrate evenly through the entire surface. The use of terracing and check dams is permissible.

- If a Basic Design is used, low-grade longitudinal slopes on the bottom and the underdrain (i.e., 0.5%) are required to ensure the system drains, but the designer must account for this grade when establishing the stone reservoir minimum depth. On especially long runs, this may result in the reservoir depth being deeper at the lower end in order to create the required storage volume.

Infiltration Sump

The infiltration sump consists of the same stone material as the reservoir layer. The depth of this layer is sized so that the Design Volume of the sump can infiltrate into the subsoil in a 48 hour period. The bottom of infiltration sump must be at least 2 feet above the seasonally high water table. The inclusion of an infiltration sump is not permitted for designs with an impermeable liner. In fill soil locations, geotechnical investigations are required to determine if the use of an infiltration sump is permissible.

PP-4.7. Underdrains

Most Permeable Pavement designs will include an underdrain (see Section PP-3). Underdrains placed at the bottom of the stone reservoir provide drainage out of the system when a Level 1 Basic Design is used. A perforated pipe placed at the top of the stone reservoir can keep detained stormwater from flooding the Permeable Pavement when runoff exceeds the capacity of the stone reservoir and bottom underdrain or infiltration. Underdrains should be used in accordance with the following:

- Minimum 0.5% slope
- Located 20 feet or less from the next pipe when using multiple pipes
- Perforated schedule 40 PVC pipe (corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center
- Encased in a layer of clean, washed No.57 stone
- Include an adjustable outlet control design such as an orifice and weir wall housed within an adjacent manhole or other structure that is easily accessed for maintenance and inspections
- Outlet control design should ensure that the stone reservoir drains slowly (recommended > 24 hours); however, it must completely drain within 48 hours.
- Level 2 Infiltration Designs can be fitted with an underdrain(s) and capped at the downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.
- Underdrain cleanouts should be provided if the pavement surface area exceeds 1,000 ft2.

PP-4.8. Observation Wells

All Permeable Pavement practices should include observation wells. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event and to facilitate periodic inspection and maintenance. The observation wells should consist of a well-anchored, perforated 4 to 6 inch (diameter) PVC pipe that is tied into any Ts or Ys in the underdrain system. The well should extend vertically to the bottom of the reservoir layer and extend upward to be flush with the surface (or just under pavers) with a lockable cap.

PP-4.9. Filter Fabric (optional)

Filter fabric is another option to protect the bottom of the reservoir layer from intrusion by underlying soils, although some practitioners recommend avoiding the use of filter fabric beneath Permeable Pavements since it may become a future plane of clogging within the system. Designers should evaluate the paving application and refer to AASHTO M288-06 for an appropriate fabric specification. AASHTO M288-06 covers six geotextile applications: Subsurface Drainage, Separation, Stabilization, Permanent Erosion Control, Sediment Control and Paving Fabrics. However, AASHTO M288-06 is not a design guideline. It is the engineer's responsibility to choose a geotextile for the application that takes into consideration site-specific soil and water conditions. Fabrics for use under permeable pavement should at a minimum meet criterion for Survivability Classes (1) and (2).

PP-4.10. Impermeable Liner

This material should be used where deemed necessary by a geotechnical investigation, such as in fill applications, karst, adjacent to building foundations, etc. Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile.

PP-4.11. Signage

Permeable Pavement applications should include signage in highly visible locations, especially near entrances to identify the pavement as being permeable and having very specific limitations on potential operation and maintenance activities. Specific activities common to most parking lots should be clearly identified as being prohibited, such as winter sanding, seal coating, etc.

4.2.4. Permeable Pavement (PP)

PP-5. Materials Specifications

Permeable Pavement material specifications vary according to the specific pavement product selected. A general comparison of different Permeable Pavements is provided in **Table PP-5** below, but designers should consult manufacturer's technical specifications for specific criteria and guidance. **Table PP-6** describes general material specifications for the component structures installed beneath the Permeable Pavement. Note that the size of stone materials used in the reservoir and filter layers may differ depending on the type of surface material.

Table PP-5. Different Permeable Pavement Specifications

Material	Specification	Notes
Permeable Interlocking Concrete Pavers (PICP)	Surface open area: 5% to 15%. Thickness: 3.125 inches for vehicles. Compressive strength: 55 Mpa. Open void fill media: aggregate	Must conform to ASTM C936 specifications. Reservoir layer required to support the structural load.
Concrete Grid Pavers	Open void content: 20% to 50%. Thickness: 3.5 inches. Compressive strength: 35 Mpa. Open void fill media: aggregate, topsoil and grass, coarse sand.	Must conform to ASTM C1319 specifications. Reservoir layer required to support the structural load.
Plastic Reinforced Grid Pavers	Void content: depends on fill material. Compressive strength: varies, depending on fill material. Open void fill media: aggregate, topsoil and grass, coarse sand.	Reservoir layer required to support the structural load.

Material	Specification	Notes
Pervious Concrete (PC)	Void content: 15% to 25 %. Thickness: typically 4 to 8 inches. Compressive strength: 2.8 to 28 Mpa. Open void fill media: None	May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or infiltration.
Porous Asphalt (PA)	Void content: 15% to 20 %. Thickness: typically 3 to 7 in. (depending on traffic load). Open void fill media: None.	Reservoir layer required to support the structural load.

Table PP-6. Material Specifications for Underneath the Pavement Surface

Material	Specification	Notes
Bedding Layer	PICP: 2 in. depth of No. 8 stone over 3 to 4 inches of No. 57 stone PC: None PA: 2 in. depth of No. 8 stone	ASTM D448 size No. 8 stone (e.g., 3/8 to 3/16 inch in size). Should be double-washed and clean and free of all fines.
Reservoir Layer	PCIP: No. 2, 3, or 4 stone subbase PC: No. 57 stone PA: No. 2 stone	ASTM D448 size No. 57 stone (e.g. 1- 1/2 to 1/2 inch in size); No. 2 Stone (e.g. 3 inch to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Should be double-washed and clean and free of all fines.
Underdrain	Use 4 to 6 inch diameter perforated PVC pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center. Perforated pipe installed for the full length of the Permeable Pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. Ts and Ys installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.	
Infiltration Sump (optional)	An aggregate storage layer below the underdrain invert. The depth of the reservoir layer above the invert of the underdrain must be at least 12 inches. The material specifications are the same as reservoir layer	

Material	Specification	Notes
Non-woven Geotextile (optional)	AASHTO M288-06 Paving Fabrics Survivability Classes (1) and (2)	
Impermeable Liner (optional)	Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile. Note: This is used only in fill soils as determined by a geotechnical investigation.	
Observation Well	Use a perforated 4 to 6 inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface or just beneath PICP.	

4.2.4. Permeable Pavement (PP)

PP-6. Design Adaptations

PP-6.1. Karst Terrain

Permeable Pavement Level 2 Infiltration and Infiltration Sump Designs are not recommended in any area with a moderate or high risk of sinkhole formation. Level 1 Basic Designs that meet separation distance requirements should work well. A geotechnical investigation and recommendations should be reviewed to consider whether an impermeable bottom liner is necessary. In general, small-scale applications of Permeable Pavement (drainage areas not exceeding one-half acre) are preferred in karst areas in order to prevent possible sinkhole formation.

PP-6.2. Steep Slopes

Permeable Pavement can be used on sites with steep slopes; provided the paved areas are terraced and maintain maximum slopes. A geotechnical evaluation should also evaluate the need for impermeable liner on the sides of the stone reservoir to minimize saturation of soils adjacent to steep slopes.

PP-6.3. Cold Climate and Winter Performance

The prevalence of sanding and salting operations create additional hazards for Permeable Pavement installations. Since the pavement itself is the pretreatment mechanism for the stone reservoir and infiltration design, precautions such as signage near the entrances to the pavement should specifically warn against applying sand or other grit to the pavement.

Research at the University of New Hampshire Stormwater Center (UNHSC) indicates that Permeable Pavement has a higher frictional resistance than standard pavements and therefore requires less sand and/or salt to maintain braking distance and safety. Further, the internal thermal convection of subsurface ground temperatures serves to warm the Permeable Pavement section faster than regular pavement, thereby minimizing the need to apply chemicals or salt to accelerate melting. (Roseen et al. 2006.)

Finally, UNHSC research on Permeable Pavement's durability in cold weather is ongoing with positive results. Properly constructed Permeable Pavements structural durability is comparable to traditional pavement materials (Roseen and Ballestero,2008.). Design variations may include extending the stone reservoir to below the frost line.

PP-6.4. Stormwater Retrofitting

Permeable Pavement is a versatile retrofitting practice that can be applied in any situation where the existing pavement may require repair or replacement. Considerations include determining if there is enough hydraulic head available to tie underdrains into an existing drainage structure or to daylight. Many retrofit practices cannot meet the full sizing requirements outlined in Section PP-4.1, so it is important to define retrofit objectives and the desired design volume necessary to meet TMDL or watershed restoration goals.

For more information on retrofitting, see the Center for Watershed Protection's manual, Urban Stormwater Retrofit Practices (Schueler et al., 2007).

4.2.4. Permeable Pavement (PP)

PP-7. Construction & Installation

PP-7.1. Erosion and Sediment Controls

The following erosion and sediment control guidelines must be followed during construction:

- Permeable Pavement areas should be clearly marked on all construction documents and grading plans.
- Any area of the site intended ultimately to be a Permeable Pavement area should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment.
- If adjacent pervious (turf or landscaped areas) are designed to drain to Permeable Pavement, the Permeable Pavement areas should be fully protected from sediment intrusion by silt fence.
- During and immediately after construction of the Permeable Pavement, care should be taken to avoid tracking sediments onto any Permeable Pavement surface to avoid clogging.
- Any area of the site intended ultimately to be a Permeable Pavement area should generally not be used as the site of a temporary sediment basin. Where locating a sediment basin on an area intended for Permeable Pavement is unavoidable, the invert of the sediment basin must be a minimum of 2 feet above the final design elevation of the bottom of the aggregate reservoir course. All sediment deposits in the excavated area should be carefully removed prior to installing the sub-base, base and surface materials.

PP-7.2. Permeable Pavement Installation

The following is a typical construction sequence to properly install Permeable Pavement, which may need to be modified depending on the specific variant of Permeable Pavement that is being installed.

Step 1. Construction of the Permeable Pavement shall only begin after the entire CDA has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow, and do not install frozen aggregate materials.

Step 2. As noted above, temporary erosion and sediment controls are needed during installation to divert stormwater away from the Permeable Pavement area until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed Permeable Pavement area must be kept free from sediment during the entire construction process. Construction materials contaminated by sediments must be removed and replaced with clean materials.

Step 3. Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions. For small pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the Permeable Pavement area (to avoid compaction). Contractors can utilize a cell construction approach, whereby the proposed Permeable Pavement area is split into 500 to 1000 sq. ft. temporary cells with a 10 to 15 foot earth bridge in between, so cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

Step 4. The native soils along the bottom of the Permeable Pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of stone. In large scale paving applications with weak soils, the soil subgrade may need to be compacted to 95% of the Standard Proctor Density to achieve the desired load-bearing capacity. (NOTE: This effectively eliminates the infiltration function of the installation, and it must be addressed during hydrologic design).

Step 5. Filter fabric should be placed as required by the design. This is typically only on the sides of the reservoir layer. Filter fabric should never be placed below the reservoir stone layer. In some cases, an impermable layer, as described in Section PP-4.10 Permeable Pavement Design Criteria may be warranted. Impermeable liner material should be installed in accordance with the manufacturer's instructions with regard to seams, overlap, sides, etc.

Step 6. Provide a minimum of 2 inches of aggregate above and below the underdrains. The underdrains should slope down toward the outlet at a grade of 0.5% or steeper. The up-gradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there shall be no perforations within 1 foot of the structure. Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.

Step 7. Moisten and spread 6-inch lifts of the appropriate clean, washed stone aggregate (usually No. 2 or No. 57 stone). Place at least 4 inches of additional aggregate above the underdrain, and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate. Do not crush the aggregate with the roller.

Step 8. Install the desired depth of the bedding layer, depending on the type of pavement, as follows:

- **Pervious Concrete:** No bedding layer is used.
- **Porous Asphalt:** The bedding layer for Porous Asphalt pavement consists of 1 to 2 inches of clean, washed ASTM D 448 No.57 stone.
- **Permeable Interlocking Concrete Pavers:** The bedding layer for open-jointed pavement blocks should consist of 2 inches of washed ASTM D 448 No.8 stone.

Step 9. Paving materials shall be installed in accordance with manufacturer or industry specifications for the particular type of pavement.

- **Installation of Porous Asphalt.** The following has been excerpted from various documents, most notably Jackson (2007).
  - o nstall Porous Asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course. The laying temperature should be between 230oF and 260oF, with a minimum air temperature of 50oF, to ensure the surface does not stiffen before compaction.
  - o Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.
  - o The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM 1664. If the estimated coating area is not above 95%, additional anti-stripping agents must be added to the mix.
  - o Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.
  - o Test the full permeability of the pavement surface by application of clean water at a rate of at least five gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.
  - o Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding, to determine the facility is draining properly.

- **Installation of Pervious Concrete.** The basic installation sequence for Pervious Concrete is outlined by the American Concrete Institute (2008). It is strongly recommended that concrete installers successfully complete a recognized Pervious Concrete installers training program, such as the Pervious Concrete Contractor Certification Program offered by the National Ready Mixed Concrete Association (NRMCA). The basic installation procedure is as follows:
  - o Drive the concrete truck as close to the project site as possible.
  - o Water the underlying aggregate (reservoir layer) before the concrete is placed, so the aggregate does not draw moisture from the freshly laid Pervious Concrete.
  - o After the concrete is placed, approximately 3/8 to 1/2 inch is struck off, using a vibratory screed. This is to allow for compaction of the concrete pavement.
  - o Compact the pavement with a steel pipe roller. Care should be taken to ensure over-compaction does not occur.
  - o Cut joints for the concrete to a depth of 1/4 inch.
  - o The curing process is very important for Pervious Concrete. Cover the pavement with plastic sheeting within 20 minutes of the strike-off, and keep it covered for at least seven (7) days. Do not allow traffic on the pavement during this time period.
  - o Remove the plastic sheeting only after the proper curing time. Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding, to determine the facility is draining properly.

- **Installation of Interlocking Pavers.** The basic installation process is described in greater detail by Smith (Smith 2011). Permeable paver job foremen should successfully complete the PICP Installer Technician Course training program offered by the Interlocking Concrete Pavement Institute. The following installation method also applies to clay paving units. Contact manufacturers of composite units for installation specifications.
  - o Moisten, place and level the No. 2 stone subbase and compact it in minimum 12 inch thick lifts with four passes of a 10-ton steel drum static roller until there is no visible movement. The first two passes are in vibratory mode with the final two passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
  - o Place edge restraints before the base layer, bedding and pavers are installed. Permeable interlocking pavement systems require edge restraints to prevent vehicle loads from moving the pavers. Edge restraints may be standard concrete curbs or curb and gutters.
  - o Moisten, place and level the No. 57 base stone in a single lift (4 inches thick). Compact it into the reservoir course beneath with at least four (4) passes of a 10-ton steel drum static roller until there is no visible movement. The first two passes are in vibratory mode, with the final two passes in static mode.
  - o Place and screed the bedding course material (typically No. 8 stone, 2 inches thick).
  - o Pavers may be placed by hand or with mechanical installers.
  - o Fill gaps at the edge of the paved areas with cut pavers or edge units. When cut pavers are needed, cut the pavers with a paver splitter or masonry saw. Cut pavers no smaller than one-third (1/3) of the full unit size if subject to tires.
  - o Fill the joints and openings with stone. Joint openings must be filled with No. 8, 89 or 9 stone per the paver manufacturer's recommendation. Sweep and remove excess stones from the paver surface.
  - o Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000 lbf, 75- to 95 Hz plate compactor. Do not compact within 6 feet of the unrestrained edges of the pavers.
  - o Thoroughly sweep the surface after construction to remove all excess aggregate.
  - o Inspect the area for settlement. Any paving units that settle must be reset and inspected.
  - o The contractor should return to the site within 6 months to top up the paver joints with stones.

PP-7.3. Construction Inspection

Inspections before, during and after construction are needed to ensure Permeable Pavement is built in accordance with these specifications. Use detailed inspection checklists that require sign-offs by qualified individuals at critical stages of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent. An example construction phase inspection checklist for Permeable Pavement practices can be found in **Appendix A**.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of Permeable Pavement installation:

- Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
- The CDA should be stabilized prior to directing water to the Permeable Pavement area.
- Check the aggregate material to confirm it is clean and washed, meets specifications and is installed to the correct depth.
- Check elevations (e.g., the invert of the underdrain, inverts for the inflow and outflow points, etc.) and the surface slope.
- Make sure the Permeable Pavement surface is even, runoff evenly spreads across it, and the storage bed drains within 48 hours.
- Ensure caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Inspect the pretreatment structures (if applicable) to make sure they are properly installed and working effectively.
- Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

It may be advisable to divert the runoff from the first few runoff-producing storms away from larger Permeable Pavement applications, particularly when up-gradient conventional asphalt areas drain to the Permeable Pavement. This can help reduce the input of fine particles often produced shortly after conventional asphalt is laid down.

4.2.4. Permeable Pavement (PP)

PP-8. Maintenance Criteria

PP-8.1. Maintenance Considerations

Maintenance is a crucial element to ensure the long-term performance of Permeable Pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment. Periodic street sweeping will remove accumulated sediment and help prevent clogging; however, it is also critical to ensure that surrounding land areas remain stabilized.

The following tasks must be avoided on ALL Permeable Pavements:

- sanding
- re-sealing
- re-surfacing
- power washing
- storage of snow piles containing sand
- storage of mulch or soil materials
- construction staging on unprotected pavement

It is difficult to prescribe the specific types or frequency of maintenance tasks that are needed to maintain the hydrologic function of Permeable Pavement systems over time. The frequency of maintenance will depend largely on the pavement use, traffic loads, and the surrounding land use.

One preventative maintenance task for large-scale applications involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the parking lot. Many consider an annual, dry-weather sweeping in the spring months to be important. **The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging**.

Recommended maintenance tasks are outlined in **Table PP-7**.

Table PP-7. Recommended maintenance tasks for Permeable Pavement practices.

Maintenance Tasks	Frequency[1]
• For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization.	After installation
• Mow grass in grid paver applications	At least 1 time every 1-2 months during the growing season
• Stabilize the CDA to prevent erosion • Remove any soil or sediment deposited on pavement. • Replace or repair any necessary pavement surface areas that are degenerating or spalling	As needed
• Vacuum pavement with a standard street sweeper to prevent clogging	2-4 times per year (depending on use)
• Conduct a maintenance inspection • Spot weeding of grass applications	Annually
• Remove any accumulated sediment in pre-treatment cells and inflow points	Once every 2 to 3 years
• Conduct maintenance using a regenerative street sweeper • Replace any necessary joint material	If clogged

[1] *Required frequency of maintenance will depend on pavement use, traffic loads, and surrounding land use.*

PP-8.2. Winter Maintenance

Winter maintenance on Permeable Pavements is similar to standard pavements, with a few additional considerations:

- Large snow storage piles should be located in adjacent grassy areas so that sediments and pollutants in snowmelt are partially treated before they reach the Permeable Pavement.
- Sand or cinders should not be applied for winter traction over Permeable Pavement or areas of standard (impervious) pavement that drain toward Permeable Pavement, since it will quickly clog the system. If applied, the materials must be removed by vacuuming in the spring.
- When plowing plastic reinforced grid pavements, snow plow blades should be lifted 1/2 inch to 1 inch above the pavement surface to prevent damage to the paving blocks or turf. Porous Asphalt, Pervious Concrete and Permeable Interlocking Concrete Pavers can be plowed similar to traditional pavements, using similar equipment and settings.
- Owners should be judicious when using chloride products for deicing over all Permeable Pavements designed for infiltration, since the salts will most assuredly be transmitted into the groundwater. Salt can be applied but environmentally sensitive deicers are recommended. Permeable Pavement applications will generally require less salt application than traditional pavements.

Maintenance agreements must be executed between the owner and the local authority. The agreements will specify the property owner's primary maintenance responsibilities and authorize local agency staff to access the property for inspection or corrective action in the event that proper maintenance is not preformed.

All Permeable Pavement areas must be covered by a drainage easement to allow inspection and maintenance by local authority staff.

When Permeable Pavements are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a maintenance agreement as described above.

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each Permeable Pavement site, particularly at large-scale applications. Example maintenance inspection checklists for Permeable Pavements can be found in **Appendix A**.

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GS-1. Introduction

Grass Swales are vegetated open channels that are designed to manage the runoff by reducing the depth of flow and velocity through the channel.

Grass Swales can be used to:

- Partially manage the first one inch of rainfall on-site using a Grass Swale designed to the required geometry and slope to maintain the Design Volume flow depth and velocity. Grass Swales can be used in all Hydrologic Soil Groups (HSGs); Soil Amendments can be used to enhance performance in HSGs C and/or D. (See **Table GS-1**)
- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs; See **Table GS-2**)
- Retrofit existing developed areas and existing drainage channels.

Grass Swales can be blended into the landscape and drainage infrastructure design for many sites. The left photo above shows a Grass Swale collecting runoff along its length from the adjacent parking lot, and the right photo shows a Grass Swale designed to manage runoff that enters at a single location at the upstream end.

Figure GS-1 further illustrates typical Grass Swale applications. **Figure GS-2** is a schematic of a typical Grass Swale. **Tables GS-1 and GS-2** describe two levels of Grass Swale design and associated volume reduction and pollutant removal performance rates. **Table GS-3** is a Design Checklist to help guide the design process for Grass Swales.

GS-1.1. Planning This Practice

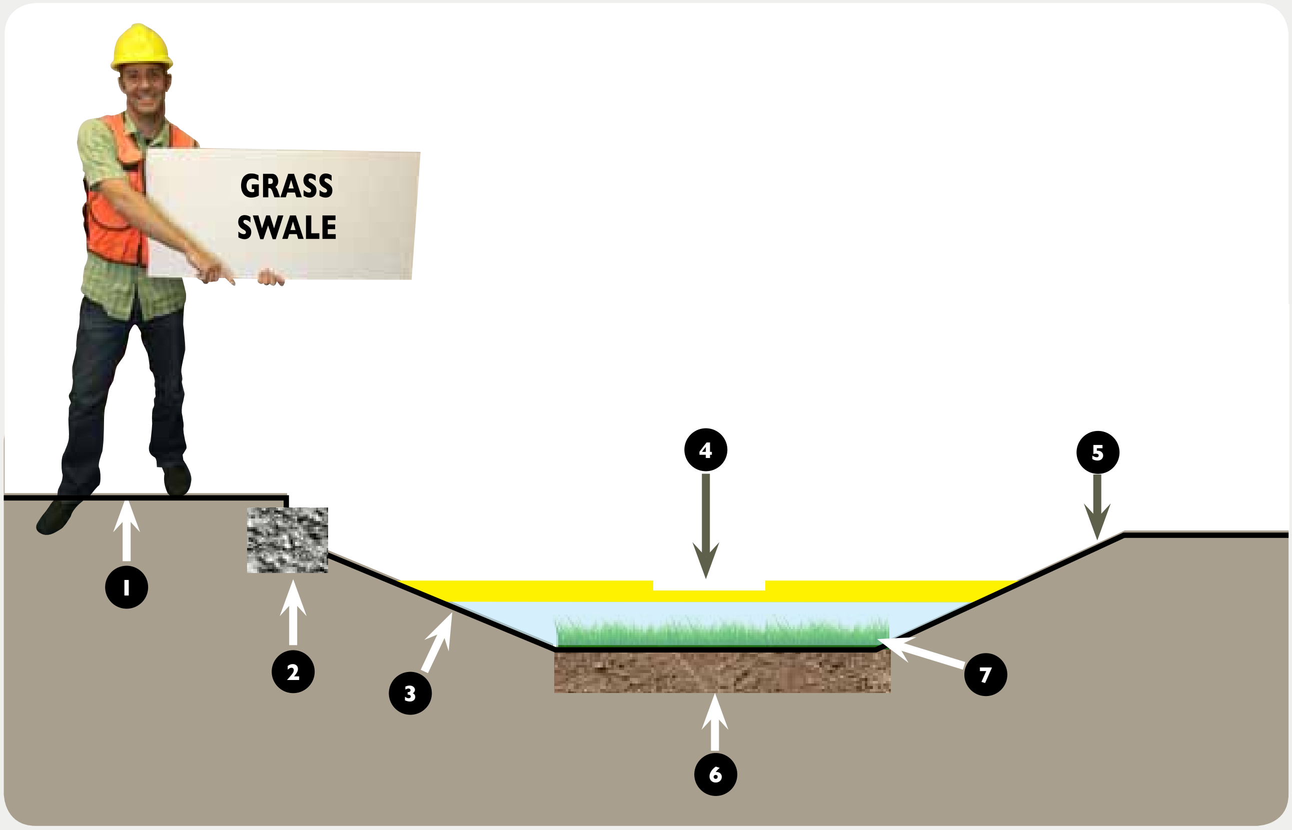
Figure GS-1. Typical Applications of Grass Swales

Edge of a Roadway

Roadway Median

Residential Application

Figure GS-2. Schematic Section for Typical Grass Swale



1. **Contributing impervious or pervious area (e.g., roadway)** – Section GS-3
2. **Pretreatment (typical gravel diaphragm)** – Sections GS-4.2
3. **Swale sizing, conveyance, geometry** – Table GS-1, Sections GS-4.1, GS-4.3 & GS-4.4
4. **Check dam with notch weir; ponding depth** – Sections GS-4.5 & GS-4.6
5. **Side slopes** – Section GS-4.7
6. **Soil Amendments (options)** – Section GS-4.8
7. **Grass swale planting** – Section GS-4.9

GS-1.2. Grass Swale Design Options & Performance

Table GS-1 describes the design and site constraints that are directly related to Grass Swale performance in terms of reducing the volume associated with one inch of rainfall on the site. Grass Swales are one of the few practices that do not use a Level 1 and Level 2 designation. Rather, the designer can implement Soil Amendments (described in detail in **Appendix D**) to overcome the basic site constraints of soil types (HSGs C or D) that would otherwise limit the performance of the practice. In addition, regardless of the soil types, the designer can manipulate the design geometry by adjusting the swale dimensions and/or adding check dams to achieve the key design criteria related to performance. **Table GS-2** summarizes pollutant removal performance values for different designs. This is for the purpose of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans.

Table GS-1. Grass Swale Design Levels: Descriptions & Performance

Hydrologic Soil Group	Description	Applications	Performance[1]
A /B	**Standard Design** – Swale Geometry: • Trapezoid • Bottom width ≥ 2 ft. • Side Slopes 3:1 maximum • Combined slope and geometry to maintain max Design Volume[2] flow velocity: ≤ 1 ft/s • Inflow energy dissipation/ pre-treatment	Generally low to moderate density development projects Sites with steep slopes can utilize check dams to break up longitudinal slope and control flow velocity.	0.20 inches for the contributing drainage area and land cover types draining to the swale[3], when designed according to minimum criteria[4]
C /D	**Standard Design** – Same as A/B soils	See above	0.10 inches for the contributing drainage area and land cover types draining to the swale[3], when designed according to minimum criteria[4]
	Standard Design w Soil Amendments (Appendix D of Manual)	See above	0.20 inches for the contributing drainage area and land cover types draining to the swale[3], when designed according to minimum criteria[4]

[1] *Performance achieved toward reducing one inch of rainfall*

[2] *The Design Volume is based on the size and land cover types of the contributing drainage area to the Grass Swale, and is used to determine a peak flow used for swale design. See* **Section GS-4** *for sizing details.*

[3] *0.20 inches x size of contributing drainage area x volumetric runoff coefficient for the drainage area. This volume can be determined by using the Design Compliance Spreadsheet. See* **Chapter 3 of this Manual** *for the calculation methodology and* **Section GS-4** *for sizing details.*

[4] *Minimum criteria address multiple design geometry characteristics related to flow depth, velocity, length, width, and residence time of water in the swale. Check dams in the channel help to reduce the effective velocity and depth of flow so as to meet the minimum criteria on steep sites, but do not provide additional volume reduction (additional storage behind check dams may be able to provide storage benefits for single storm event modeling). See* **Section GS-4** *for sizing details.*

Table GS-2. Total Pollutant Load Reduction Performance Values for Grass Swales

Hydrologic Soil Group	Total Suspended Solids (TSS)[1]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)[1]
A/B	TSS = 60%	TP = 32% TN = 36%
C/D	TSS = 35%	TP = 23% TN = 28%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008).

GS-1.3 Grass Swale Design Checklist

Table GS-3. Grass Swale Design Checklist

CHECKLIST

This checklist will help the designer through the necessary design steps for Grass Swales

- ☐ Check feasibility for site – **Section GS-3**
- ☐ Evaluate site constraints and determine HSGs present on site and evaluate feasibility of achieving design goals: swale geometry and slope to meet maximum allowed flow depth and velocity.– **Table GS-1**
- ☐ Verify Grass Swale sizing guidance and ensure adequate footprint on the site for Grass Swale(s) – **Section GS-4.1**
- ☐ Complete Design Compliance Spreadsheet and confirm if additional practices are needed for overall site compliance – **Spreadsheet & Chapter 3 of Manual**
- ☐ Check design adaptations appropriate to the site – **Section GS-6**
- ☐ Design Grass Swale in accordance with design criteria and typical details – **Sections GS-2 & GS-4**
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, construction sequence, and notes

4.2.5. Grass Swale (GS)

GS-2. Typical Details

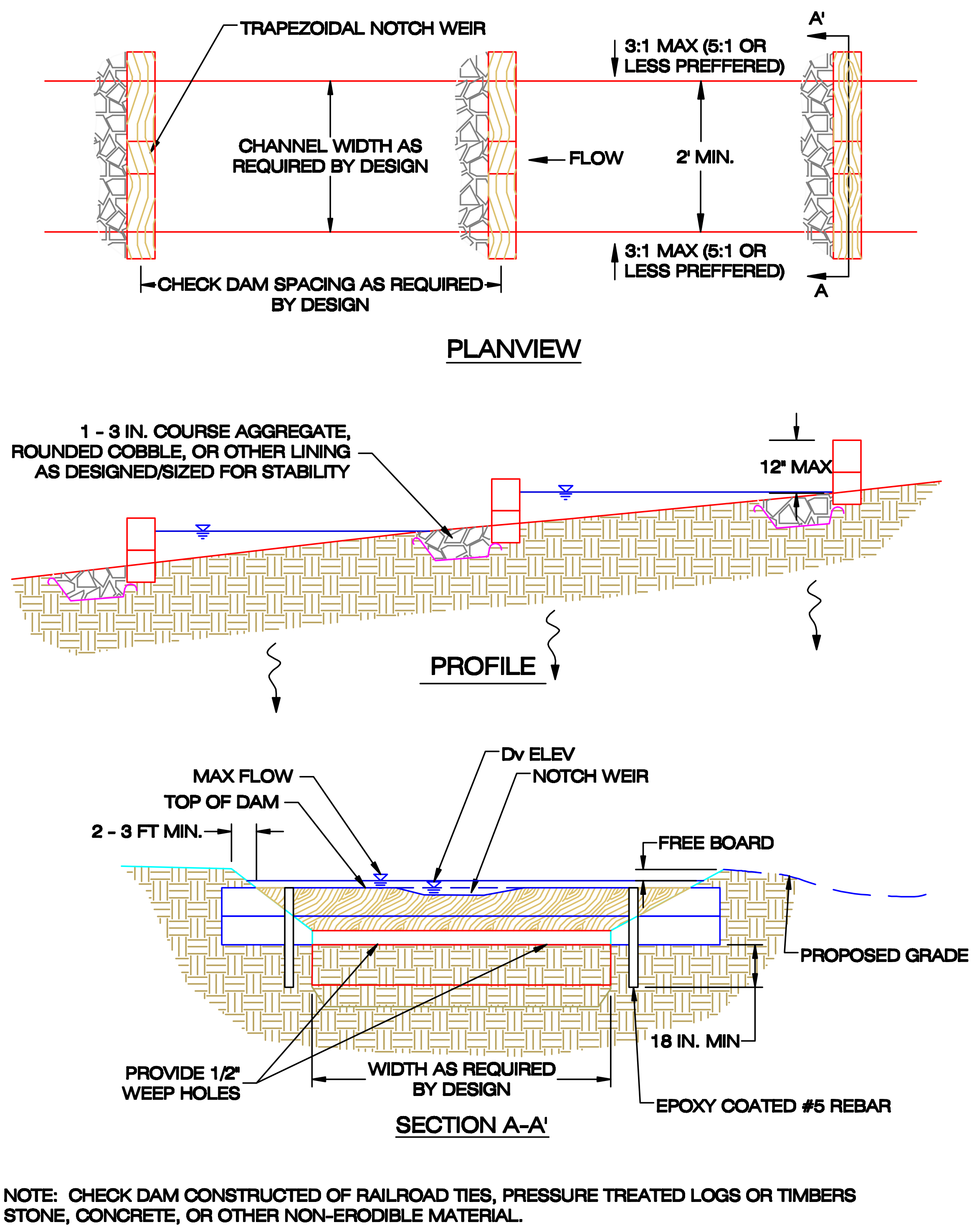


Figure GS-3. Typical Detail for Grass Swale with Check Dams

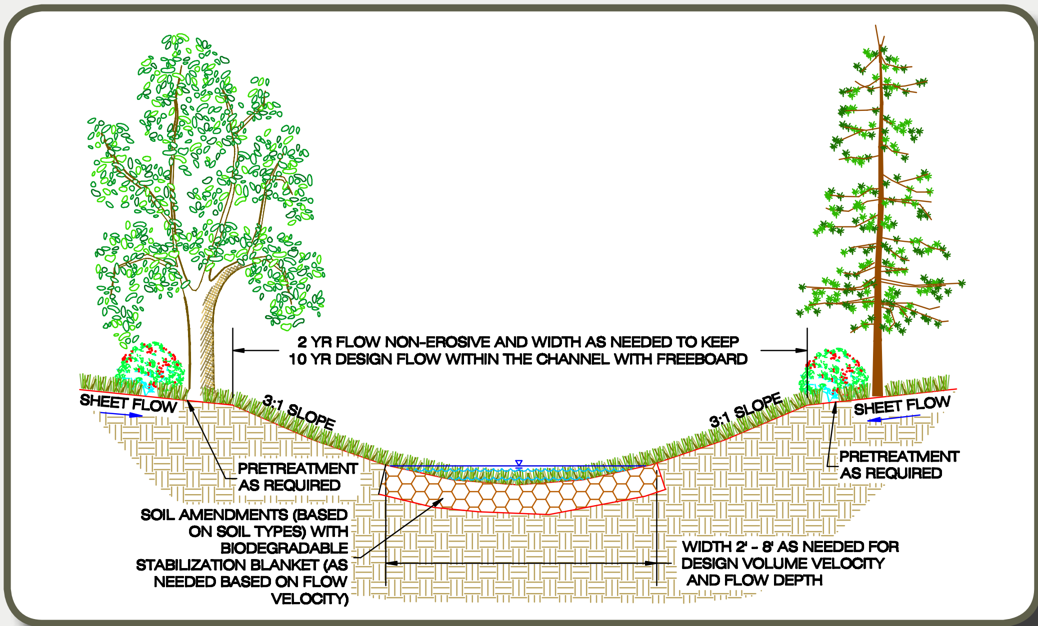


Figure GS-4. Typical Detail for Grass Swale with Soil Amendments

4.2.5. Grass Swale (GS)

GS-3. Feasibility Criteria and Design Considerations

Grass Swales are primarily applicable for land uses such as roads, highways, and residential development. Key constraints with Grass Swales include the following:

Available Space. Grass Swales can be incorporated into linear development applications (e.g., roadways) by utilizing the footprint typically required for an open section drainage system. The footprint required will likely be greater than that of a typical conveyance channel because of the limitations on velocity and depth of flow. However, the benefit of the runoff reduction may reduce the footprint requirements for stormwater management elsewhere on the development site.

Site Topography. Grass Swales must be constructed at relatively flat grades, so they are most effective on sites with mild to moderate post-construction grades (less than 5%). Check dams can be used to reduce the effective slope of the channel and lengthen the contact time to enhance filtering and/or infiltration. Longitudinal slopes of less than 2% are ideal and may eliminate the need for check dams. However, channels designed with longitudinal slopes of less than 1% should be monitored carefully during construction to ensure a continuous grade, in order to avoid flat areas with pockets of standing water.

Available Hydraulic Head. A minimum amount of hydraulic head is needed to implement Grass Swales in order to ensure positive drainage and conveyance through the channel. The hydraulic head is measured as the elevation difference between the channel surface inflow and outflow point.

Water Table. Designers should ensure that the bottom of Grass Swales is at least 1 foot above the groundwater table to ensure that the seasonally high groundwater does not intersect the swale flow line (which would likely render the design a "wet swale" – refer to **Design Specification 4.2.11, Stormwater Wetlands**).

Soils and Underdrains. Grass channels are suitable for most soil types as long as they can support a good stand of vegetation. Soil Amendments are recommended in HSGs C and D (see **Section GS-4.8** of this Specification and **Appendix D**)

Contributing Drainage Area. The maximum recommended contributing drainage area (CDA) to Grass Swales is 5 acres, and preferably less. Grass Swales managing runoff from drainage areas greater than 5 acres must still address conveyance design criteria for larger storms which will often overwhelm the design elements intended to manage the

Design Volume. The larger storm events will require significant channel cross sections in order to keep velocities down and prevent erosion in the channel. The design criteria for maximum channel velocity and depth are applied along the entire length (See Section GS-4).

Hotspot Land Uses. Grass Swales can typically be used to convey runoff from stormwater hotspots, but do not qualify as a hotspot treatment mechanism.

For a list of potential stormwater hotspots, please consult **Chapter 5 of the Manual**.

Use of Grass Swales in Fill Sections or On Marginal Soils

In areas of fill, soil slips can result from saturating sections of different soil types. While Grass Swales are not necessarily designed to infiltrate runoff, they can attenuate flows so as to encourage infiltration where soils allow. Grass Swales can be used in either cut or fill, however a clear note should address proper fill material preparation in order to minimize any differential soil conditions.

Further, Grass Swales depend on dense vegetation to promote filtering and abstraction. Construction of Grass Swales in fill material or in a disturbed soil profile may require Soil Amendments in order to establish vegetation and achieve even basic performance. A soil test should be performed to evaluate the organic content and fertilization requirements.

Floodplains. Grass Swales should be constructed outside the limits of the mapped 100-year floodplain, unless a waiver is obtained from the local authority.

Baseflow and Non-stormwater Discharges. Grass Swales should be located so as to avoid inputs of springs, chlorinated wash-water, or other dry weather flows. Periodic irrigation runoff is permissible, however too much discharge may impact the vegetation.

Setbacks. Grass Swales should be set back at least 10 feet down-gradient from building foundations. Similarly, setbacks from septic system fields and private wells are typically needed only to avoid impacting the function of those systems during construction and potential maintenance of the swale. Generally, minimum setbacks of 10 to 20 feet from the perimeter of drain fields and well heads is recommended.

Proximity to Utilities. Approval from the applicable utility company or agency is required if utility lines will run below or through Grass Swale areas. Typically, utilities can cross linear channels perpendicular if they are protected (e.g., double-casing or conduit). Locating utilities (especially water and sewer lines) in a parallel alignment under a Grass Swale is not recommended.

Community Factors. The main concerns of adjacent residents are perceptions that Grass Swales will create nuisance conditions or will be hard to maintain. Common concerns include the continued ability to mow grass, landscape preferences, weeds, standing water, and mosquitoes. All of these concerns can be fully addressed through the design and construction process and proper on-going operation and routine maintenance. Grass Swales should be placed in a drainage or maintenance easement in order to ensure long term maintenance (see Section GS-8 Maintenance)

Underground Injection Permits. Grass Swales are not considered to be Class V wells subject to permits under the Underground Injection Control (UIC) Program (U.S. EPA, 2008).

4.2.5. Grass Swale (GS)

GS-4. Design Criteria

GS-4.1. Grass Swale Sizing Guidelines for Water Quality & Volume Reduction

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a best management practice (BMP) plan:

Target Treatment Volume (Tv) = Volume associated with managing 1" of rainfall based on the size and land cover of the CDA, as determined by the Design Compliance Spreadsheet. Any given BMP may treat the full Tv or only part of it if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on storage (or peak flow in the case of Grass Swales), as prescribed in the BMP specification. Grass Swales are often part of a treatment train BMP design, with possible upgradient (e.g., Impervious Surface Disconnection) and downgradient (e.g., Bioretention) practices. In these cases, the Dv of the Grass Swale may be a portion of the overall Tv for the contributing drainage area. In such cases, the sum of the Design Volumes in the Grass Swale plus that of the other practices in the treatment train should equal the total drainage area Tv. On the other hand, when Grass Swales are the last practice in a treatment train, the designer may have to accommodate all the flow from the CDA, including large storm bypass from the upstream practices. In these cases, the swale is likely oversized and the Dv will be at least equal to the CDA Tv, and the credit will be 0.2 watershed inches as described in Table GS-1.

See **Chapter 3** for more information on the runoff reduction design methodology.

For the purposes of this sizing section, the sizing relates to the Dv of the Grass Swale being designed.

Unlike other stormwater practices, Grass Swales are designed based on a peak rate of flow. Designers must demonstrate both channel conveyance and treatment capacity in accordance with the following guidelines:

- Hydraulic capacity should be verified using Manning's Equation or an accepted equivalent method, such as erodibility factors and vegetal retardance.
  - The flow depth for the peak flow generated by the Design Volume should be maintained at 4 inches or less, with a flow velocity ≤ 1 ft/s.
  - Manning's "n" value for Grass Swales should be 0.2 for flow depths up to 4 inches, decreasing to 0.03 at a depth of 12 inches and above (which would apply to the 2-year/24 hour storm. and 10-year storms if an on-line application as noted in Haan et. al, 1994).
  - Peak flow rates for the 2-year frequency storm must be non-erosive, in accordance with **Table GS-5** below (see **Section GS-4.9 Grass Swale Landscaping Criteria**), or subject to a site-specific analysis of the channel lining material and vegetation; and the 10-year peak flow rate must be contained within the channel banks (with a minimum of 0.3 feet of freeboard).
- Calculations for peak flow depth and velocity should reflect any increase in flow along the length of the swale, as appropriate. If a single flow is used, the flow at the outlet should be used.
- The hydraulic residence time (the time for runoff to travel the full length of the channel) should be a minimum of 9 minutes for the peak flows from the Design Volume storm (Mar et al., 1982; Barrett et al., 1998; Washington State Department of Ecology, 2005). If flow enters the swale at several locations, a 9 minute minimum hydraulic residence time should be demonstrated for each entry point, using **Equations GS-1 – GS-5** below.

The Grass Swale geometry is designed according to the recommended steps provided below to maintain the appropriate flow depth and velocity.

Using Available Swale Design Tools

Designers may choose to utilize available hydraulic design software to optimize the swale geometry for treatment and large storm conveyance.

1. Establish the peak flow rate for the one-inch rainfall event (Refer to **Appendix F** for guidance on the recommended calculation procedure). This will be the design peak flow rate for the entire drainage area. If the flow enters the swale at intermediate points or continuously along the length, the designer may choose to establish the maximum section at the downstream end of the swale and then work upstream establishing an incrementally smaller cross section corresponding to the incrementally smaller drainage area and peak flow rate.

Verify Modeling Approach with Local Authority

Designers should verify through the local plan approving authority if they intend to utilize a different hydrologic modeling tool or computational procedure other than that referenced in Appendix F.

2. Use the Manning equation (**Equation GS-1**) to calculate the velocity for the maximum flow depth of four inches (0.3 ft.) and the design longitudinal slope of the swale.

Equation GS-1: Manning's Equation

$$V = \left[\left(\frac{1.49}{n}\right) D^{2/3} s^{1/2}\right]$$

V = flow velocity (ft./sec.)
n = roughness coefficient (0.2, or as appropriate)
D = flow depth (ft.) (NOTE: D approximates hydraulic radius for shallow flows)
s = channel slope (ft./ft.)

3. Calculate the minimum bottom width (W) required to accommodate the design peak flow velocity (based on the four inch depth as calculated in Step 2 above) using the rearranged Continuity Equation (**Equation GS-2**):

Equation GS-2: Continuity Equation

$$Q_{Dv} = VA$$

$$Q_{Dv} = V(W \times D)$$

Rearranged Continuity Equation

$$W = Q_{Dv}/(V \times D)$$

Where:
Q_{Dv} = Design Volume design peak flow rate (cfs)
V = swale flow velocity (ft./sec.)
A = swale cross sectional flow area = $W \times D$
W = channel width (ft.)
D = flow depth (ft.)
(NOTE: channel width (W) x depth (D) approximates the cross sectional flow area for shallow flows.)

An alternative direct solution for the minimum swale bottom width is through combining **Equations GS-1 and GS-2**, and re-writing them as follows:

Equation GS-3: Minimum Width

$$W = \left[\frac{nQ_{Dv}}{\left(1.49D^{5/3}s^{1/2}\right)}\right]$$

Solving **Equation GS-2** for the corresponding velocity provides:

Equation GS-4: Corresponding Velocity

$$V = Q_{Dv}/WD$$

The width, slope, or Manning's "n" value can be adjusted to provide an appropriate channel design for the site conditions. However, if a higher density of grass is used to increase the Manning's "n" value and decrease the resulting channel width, it is important to provide material specifications and construction oversight to ensure that the more dense vegetation is actually established. Equation GS-5 can then be used to ensure adequate hydraulic residence time.

In addition, the designer should evaluate the use of check dams and the impact on the flow velocity. The velocity and resulting travel time will be lengthened based on the distance between the check dams and the ponding depth behind the check dams.

Equation GS-5: Grass Channel Length for Hydraulic

Residence Time of 9 minutes (540 seconds)

$$L = 540 * V$$

Where:
L = minimum swale length (ft.)
V = flow velocity (ft./sec.)

The runoff reduction credit is applied to the Design Volume used to establish the design of the swale.

GS-4.2. Pretreatment

Pre-Treatment is Essential

Pre-treatment is required for Grass Swales to dissipate energy and runoff velocity at concentrated inflow points and trap sediments and other particulate pollutants. Pre-treatment is essential to prolong the life of the practice and ensure long-term performance. Pre-treatment for Grass Swales can be simple practices, such as a grass strip or gravel diaphragm.

Several pre-treatment measures are feasible, depending on the type of the Grass Swale practice and whether it receives sheet flow or concentrated flow. **Figure GS-5** shows typical pretreatment options for Grass Swales. For pre-treatment structures at the edge of pavement (e.g., grass filter strips, gravel diaphragms, flow splitters), it is important that there be a 2 to 4 inch drop from the edge of pavement to the top of the grass or stone in the pre-treatment structure. This is to prevent accumulation of debris and subsequent clogging at the point where runoff is designed to enter the pre-treatment structure (see **Figure GS-6**).

Figure GS-5. Examples of Pre-Treatment Applicable to Grass Swales

Grass filter strips *that are perpendicular to incoming sheet flow extend from the edge of pavement (with a slight drop of 2 to 3 inches at the pavement edge) to the bottom of the Grass Swale at a 5:1 slope or flatter.*

This Pre-Treatment Cell is located at piped inlets or curb cuts leading to the Swale. The cell may be formed by a wooden or stone check dam or an earthen or rock berm.

Figure GS-5 (continued)

Check Dams are energy dissipation devices that can be used on small Grass Swales with drainage areas of less than 1 acre. The most common form is the use of wooden or stone check dams. The pretreatment volume stored must be 10% of the Design Volume.

A Gravel Diaphragm located at the edge of the pavement should be oriented perpendicular to the flow path to pre-treat lateral runoff, with a 2 to 4 inch drop from the pavement edge to the top of the stone. The stone must be sized according to the expected rate of discharge.

The Gravel or Stone Flow Spreader is located at curb cuts, piped inlets, downspouts, or other concentrated inflow points. The gravel or stone should extend the entire width of the opening and create a level stone weir at the bottom of the swale.

Tree Check Dams are tree mounds that are placed within the bottom of Grass Swales up to an elevation of 9 to 12 inches above the channel invert. One side has a gravel or river stone bypass to allow runoff to percolate through (Cappiella et al, 2006). The pretreatment volume stored must be 10% of the Design Volume.

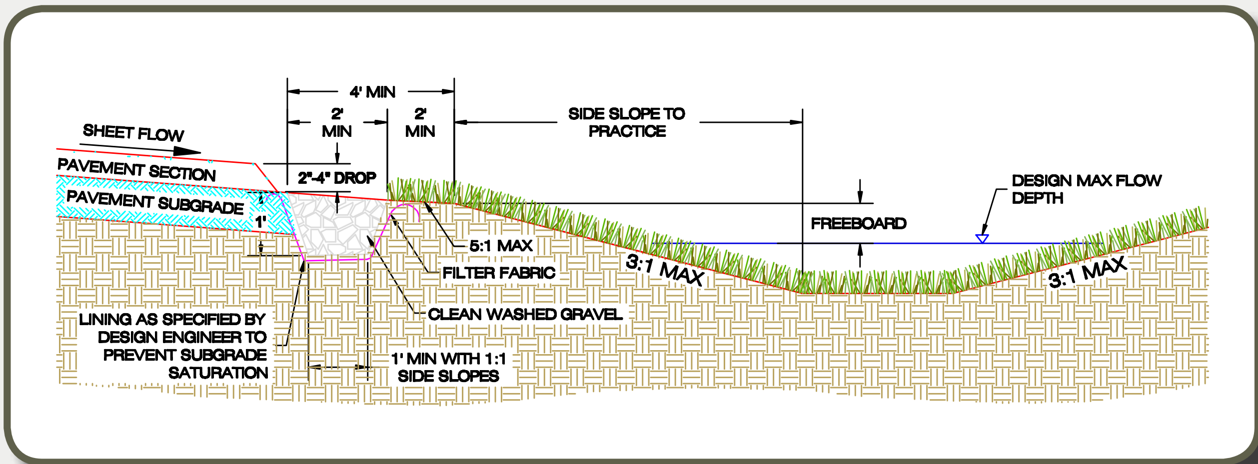


Figure GS-6. Typical Detail for Pre-Treatment at Pavement Edge – A 2 to 4 inch drop from the pavement to the top of stone helps to prevent clogging.

GS-4.3. Conveyance and Overflow

The bottom width and slope of a Grass Swale is designed to achieve the required flow depth, velocity, and travel time of the Tv for the full length of the channel. Grass Swales must also be designed to convey the 2- and 10-year storms at non-erosive velocities for the soil and vegetative cover provided (**Table GS-5**). The final swale design shall have a minimum of 0.3 ft. freeboard above the design 10-year water surface profile of the channel. The analysis should evaluate the flow profile through the channel at normal depth, as well as the flow depth over top of the check dams.

In order to avoid the additional swale cross section needed to accommodate the larger storms, designers may choose to construct the swale in an off-line configuration. This will generally require some form of a diversion structure that is specifically designed to only allow the design Tv peak flow rate into the swale.

An alternative off-line configuration incorporates a check dam design that when full (water is backed up to the maximum ponding depth) prevents additional flow from entering the swale and forces it to bypass into a large storm conveyance system. This configuration is especially useful in an edge of pavement application where the overflow can be diverted along the edge of pavement to an alternative conveyance. A single inflow design will be complicated by the need to ensure that the downstream check dams have had a chance to fill before diverting flow at the upper end.

It should be noted that both types of design approaches require attention to safe conveyance of larger flows in adequate conveyances and with adequate freeboard to a receiving waterbody. Drainage design should be based on expected peak discharges assuming that upstream stormwater BMPs are full and typically provide marginal storage during larger events. Large storm overland-flow paths should be identified and labeled in the project's overall drainage map.

GS-4.4. Design Geometry

Design guidance regarding the geometry and layout of open channels is provided below:

- Edge of pavement Grass Swales should generally be aligned adjacent to and the same length as the CDA identified for treatment.
- Grass Swales should be designed with a trapezoidal cross section. It is very common for a trapezoidal cross section to take on a parabolic shape within the first year after construction due to the margin of error related to construction and erosion and sedimentation of the side slopes during the first year of vegetation establishment.
- The bottom width of the swale should be a minimum of 2 feet wide. Typical design (depending on drainage area and longitudinal slope) will be between 2 and 8 feet wide to ensure that an adequate surface area exists along the bottom of the swale for filtering. If a swale will be wider than 8 feet, the designer should incorporate benches, check dams, level spreaders or multi-level cross sections to prevent braiding and erosion along the swale bottom.

GS-4.5. Check Dams

Check dams may be used for pre-treatment, to reduce the effective slope and flow velocity, and thereby increase the hydraulic residence time in the swale. Design requirements for check dams are as follows:

- Check dams should be spaced based on the swale slope, as needed to increase residence time, provide design storm storage volume, or any additional volume attenuation requirements. In typical spacing, the ponded water at a downhill check dam should not touch the toe of the upstream check dam.
- The maximum desired check dam height is 12 inches (for maintenance purposes). However, for some sites, a maximum of 18 inches can be allowed, with additional design elements to ensure the stability of the check dam and the adjacent and underlying soils.
- The swale should have a continuous grade between check dams.
- Armoring may be needed at the downstream toe of the check dam to prevent erosion.
- Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the swale bottom so as to prevent hydrostatic head from pushing out the underlying soils.
- Check dams must be designed with a center weir sized to pass the swale design storm peak flow (typically the 10-year storm event).
- Each check dam should have a weep hole or similar drainage feature so it can dewater after storms.

- Check dams should be composed of wood, concrete, stone, or other non-erodible material. Individual swale segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.

Check dams for Grass Swales should be spaced to reduce the effective slope to 2% or less, as provided in **Table GS-4** below.

Table GS-4. Typical Check Dam (CD) Spacing to Achieve Effective Channel Slop

Swale Longitudinal Slope	Spacing [1] of 12-inch High (max.) Check Dams [3, 4] to Create an Effective Slope of 2%	Spacing [1] of 12-inch High (max.) Check Dams [3, 4] to Create an Effective Slope of 0 to 1%
0.5%	–	200 ft. to –
1.0%	–	100 ft. to –
1.5%	–	67 ft. to 200 ft.
2.0%	–	50 ft. to 100 ft.
2.5%	200 ft.	40 ft. to 67 ft.
3.0%	100 ft.	33 ft. to 50 ft.
3.5%	67 ft.	30 ft. to 40 ft.
4.0%	50 ft.	25 ft. to 33 ft.
4.5% [2]	40 ft.	20 ft. to 30 ft.
5.0% [2]	40 ft.	20 ft. to 30 ft.

Notes:

[1] The spacing dimension is half of the above distances if a 6-inch check dam is used.

[2] Grass Swales with slopes greater than 4% require special design considerations, such as drop structures to accommodate greater than 12-inch high check dams (and therefore a flatter effective slope), in order to ensure non-erosive flows.

[3] All check dams require a stone energy dissipater at the downstream toe.

[4] Check dams require weep holes at the channel invert. Swales with slopes less than 2% will require multiple weep holes (at least 3) in each check dam.

GS-4.6. Ponding Depth

Check dams should be used in Grass Swales to create ponding cells along the length of the channel. The maximum ponding depth in a Grass Swale should not exceed 18 inches. It may be necessary or desirable to space check dams more frequently than is shown in **Table GS-**4 in order to decrease the ponding depth.

Limit Applications of 18" Ponding

Designers should evaluate the community acceptance (safety, aesthetics, etc.) and maintenance factors when considering the use of 18 inch ponding depths in a residential setting. The 18" ponding depth may be appropriate for larger-scale commercial, industrial, or institutional settings. The depth of ponding should never exceed 18".

GS-4.7. Side Slopes

Grass Swale side slopes should be no steeper than 3H:1V for ease of mowing and routine maintenance. Flatter slopes are encouraged where adequate space is available, to enhance pre-treatment of sheet flows entering the swale.

GS-4.8 Soil Amendments

Soil Amendments serve to increase the runoff reduction capability of a Grass Swale constructed on HSGs C and/or D. The following design criteria apply when Soil Amendments are used:

- The compost-amended strip should extend over the length and width of the swale bottom, and the compost should be incorporated to a depth as outlined in **Appendix D**.
- The amended area will need to be rapidly stabilized.
- It may be necessary to install a temporary or permanent erosion control blanket to protect the compost-amended soils. Care must be taken to consider the erosive characteristics of the amended soils when selecting an appropriate geotextile. Refer to the WVDEP (2006)
- For redevelopment or retrofit applications, the final elevation of the Grass Swale (following compost amendment) must be verified as meeting the original design hydraulic capacity.

GS-4.9. Grass Swale Planting Criteria

All Grass Swales must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. Several appropriate types of grasses appropriate for Grass Swales are listed in **Table GS-5**. Designers should consider the following when choosing grass cover:

- Tall and high stem density grasses that can withstand the flow velocity anticipated in the swale (designers should ensure that the maximum flow velocities do not exceed the values listed in **Table GS-5** for the selected grass species and the swale slope).
- If roadway salt will be applied to the CDA, Grass Swales should be planted with salt-tolerant plant species.
- Landscape design shall specify proper grass species based on specific site, soils and hydric conditions present along the channel.
- Grass Swales should be seeded at such a density to achieve a 90% vegetated cover after the second growing season.
- Grass Swales should be seeded and not sodded. Seeding establishes deeper roots and sod may have muck soil that is not conducive to infiltration. (Wisconsin DNR, 2004)

- Grass channels should be protected by a biodegradable erosion control fabric to provide immediate stabilization of the channel bed and banks.

For a list of grass species suitable for use in grass channels, consult WVDEP (2006) . Also, consult **Appendix F** of this manual for a comprehensive plant list for stormwater BMPs.

Table GS-5. Recommended Vegetation and Maximum Flow Velocities for Grass Swales.

Vegetation Type	Slope (%)	Maximum Velocity (ft/s)	
		Erosion resistant soil	Highly Erodible Soil[1]
Bermuda Grass	0-5	6	4.5
	5-10	5	4
	>10	4	3
Kentucky Bluegrass Reed Canary Grass Tall Fescue Grass Mixture	0-5	5	4
	5-10	4	3
	>10	3	2.5
Red Fescue Redtop	0-5	5	4

[1]An erodibility factor (K) greater than 0.35 would indicate a highly erodible soil. Erodibility (K-factors) can be obtained from local NRCS offices.

Source: WVDEP (2006)

4.2.5. Grass Swale (GS)

GS-5. Materials Specifications

Recommended material specifications for Grass Swales are shown in **Table 6**.

Table 6. Grass Swale Material Specifications

Component	Specification
Grass	A dense cover of water-tolerant, erosion-resistant grass. The selection of an appropriate species or mixture of species is based on several factors including climate, soil type, topography, and sun or shade tolerance. Grass species should have the following characteristics: a deep root system to resist scouring; a high stem density with well-branched top growth; water-tolerance; resistance to being flattened by runoff; an ability to recover growth following inundation; and, if receiving runoff from roadways, salt-tolerance.
Check Dams	• Check dams should be constructed of a non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric conforming to local design standards. • Wood used for check dams should consist of pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.
Diaphragm	Pea gravel used to construct pre-treatment diaphragms should consist of washed, open-graded, course aggregate between 3 and 10 mm in diameter and must conform to local design standards.
Erosion Control Fabric	Where flow velocities dictate, biodegradable erosion control netting or mats that are durable enough to last at least two growing seasons must be used, conforming to WVDEP (2006)

4.2.5. Grass Swale (GS)

GS-6. Design Adaptations

GS-6.1. Karst Terrain

Grass Swales are an acceptable practice in karst terrain, as long as they do not treat hotspot runoff. The following design adaptations apply to grass channels in karst terrain:

- Soil compost amendments may be incorporated into the bottom of Grass Swales to improve their runoff reduction capability.
- Check dams are generally discouraged for Grass Swales in karst terrain, since they pond too much water (although flow spreaders that are flush with the ground surface and spaced along the channel length may be useful in spreading flows more evenly across the channel width).
- The minimum depth to the bedrock layer is 12 inches.

- A longitudinal slope greater than 0.5% must be maintained to ensure positive drainage.
- The Grass Swale may have off-line cells and should be tied into an adequate discharge conveyance system.

GS-6.2. Steep Slopes

Grass Swales are not practical in areas of steep terrain, although terracing a series of Grass Swale cells may work on slopes from 5% to 10%. The drop in elevation between check dams should be limited to 18 inches in these cases, and the check dams should be armored on the down-slope side with suitably sized stone to prevent erosion.

GS-6.3. Cold Climate and Winter Performance

Many different kinds of salting and sanding materials are applied to roads and highways during winter months. Grass Swales can store snow and treat snowmelt runoff when they serve road or parking lot drainage. If roadway salt is applied in their CDA, Grass Swales should be planted with salt-tolerant species.

GS-6.4. Stormwater Retrofitting

Grass Swales can be readily used in retrofit situations. Most swale retrofits require that an existing open channel be widened, deepened, reduced in gradient, or some combination of all three. Swales are particularly well suited to treat runoff from low and medium density residential streets and small parking lots.

For more information on retrofitting, see the Center for Watershed Protection's manual, ***Urban Stormwater Retrofit Practices*** (Schueler et al., 2007).

4.2.5. Grass Swale (GS)

GS-7. Construction & Installation

GS-7.1. Construction & Installation

Grass Swale alignments may be utilized during construction as diversion dikes. However, specific plan notes regarding the clean out and conversion to a water quality swale must be specific in removing the accumulated sediment as well as minor excavation down into undisturbed soils.

A Grass Swale used to convey clean water around or through a construction should be fully protected by silt fence or diversion and protected from construction traffic crossing the swale. Ideally, Grass Swales should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical, given that the channels are a key part of the drainage system at most sites. In these cases, temporary erosion and sediment controls such as dikes, silt fences and other erosion control measures should be integrated into the swale design throughout the construction sequence.

GS-7.2. Grass Swale Installation

The following is a typical construction sequence to properly install Grass Swales, although steps may be modified to reflect different site conditions or design variations. If possible, Grass Swales should be installed at a time of year that is best to establish turf cover without irrigation.

The timing of the installation of Grass Swales is dependent on whether the swale is to be used as a conveyance during construction. It may be preferable to construct the swale prior to the CDA being directed to the swale in order to help establish vegetation in the swale bottom. If this is not feasible based on the construction sequencing of the site, then the

CDA should be stabilized with vegetation before attempting to establish vegetation in the channel.

Any accumulation of sediment that does occur within the channel must be removed during the final stages of grading or establishing vegetative cover in order to achieve the design cross-section.

Step 1. Grade the Grass Swale to the final dimensions shown on the plan. Excavators or backhoes should work from the sides to grade and excavate the swale to the appropriate design dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the open channel area. The final grading should rake or scarify the bottom as needed for seed preparation.

Step 3 (Optional). Add Soil Amendments as needed. Till the bottom of the Grass Swale to a depth of 1 foot and incorporate compost amendments according to Appendix D.

Step 4. Install check dams, driveway culverts and internal pre-treatment features as shown on the plan. The top of each check dam should be constructed level at the design elevation.

Step 5. Seed (or Hydro-seed) the bottom and banks of the open channel, and peg in erosion control fabric or blanket where needed. After initial planting, a biodegradable erosion control fabric should be used, conforming to WVDEP (2006).

Step 6. Conduct the final construction inspection and develop a punchlist for facility acceptance.

GS-7.3 Construction Inspection

Inspections during construction are needed to ensure that the Grass Swale is built in accordance with these specifications. An example construction phase inspection checklist is available in Appendix A of the Manual.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of Grass Swale installation:

- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the channel bed and side-slopes.
- Inspect check dams and pre-treatment structures to make sure they are at correct elevations, are properly installed, and are working effectively.
- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

The real test of a Grass Swale occurs after the first big storm. The post-storm inspection should focus on whether the desired sheet flow, shallow concentrated flows or fully concentrated flows assumed in the plan actually occur in the field. Minor adjustments are normally needed as part of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets, or realignment of outfalls and check dams).

4.2.5. Grass Swale (GS)

GS-8. Maintenance Criteria

Maintenance is a crucial element that ensures the long-term performance of Grass Swales. Once established, Grass Swales have minimal maintenance needs outside of the spring clean up, regular mowing, periodic repair of check dams and other measures to maintain the hydraulic efficiency of the channel and a dense, healthy grass cover. Additional effort may be needed to stabilize inlet points and remove deposited sediment from pre-treatment cells.

Periodic maintenance should be integrated into routine landscape maintenance tasks:

- If landscaping contractors will be expected to perform maintenance (as is likely on commercial, business, or high density residential land uses), their contracts should contain specifics on unique Grass Swale landscaping needs.
- If maintenance is conducted by a homeowner, they should be:
  (1) educated about their routine maintenance needs;
  (2) understand the long-term maintenance elements; and
  (3) be subject to modified maintenance agreements (as described below).

Consider Maintenance during the Design Process

A critical maintenance factor is the many design choices made during the swale design. The context of the site and maintenance capabilities of the owner(s) should be considered during the design process such as including adequate access for mowing and trash and debris removal.

As with all BMPs, maintenance agreements must be executed between the owner(s) and the local authority to ensure that the practices are maintained and function properly. The agreements will specify the property owner's primary maintenance responsibilities and authorize local agency staff to access the property for inspection or corrective action in the event that proper maintenance is not performed.

Grass Swales must be covered by a drainage easement to allow inspection and maintenance by local authority staff.

Table GS-7. Suggested Maintenance Activities and Schedule for Grass Swales

Maintenance Activity	Frequency
• Mow grass channels and dry swales during the growing season to maintain grass heights in the 4" to 6" range.	As needed
• Ensure that the CDA is clear of debris. • Ensure that the CDA is stabilized. Perform spot-reseeding if or where needed. • Repair undercut and eroded areas as needed at swale inflow and outflow structures. • Inspect upstream and downstream of check dams for evidence of undercutting or erosion, and remove and trash or blockages at weepholes.	Quarterly
• Reseed as needed during fall seeding season to maintain 90% turf cover. • Remove any accumulated sand or sediment deposits behind check dams. • Examine channel bottom for evidence of erosion, braiding, excessive ponding or dead grass. • Check inflow points for clogging and remove any sediment. • Inspect side slopes and grass filter strips for evidence of any rill or gully erosion and repair.	Annual inspection

Annual inspections are used to trigger maintenance operations such as sediment removal, spot revegetation and inlet stabilization. Example maintenance inspection checklists for disconnection can be found in **Appendix A of the Manual**.

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4.2.6. Infiltration (IN)

IN-1. Introduction

Infiltration practices capture and temporarily store runoff before allowing it to infiltrate into the underlying soil over a period of approximately two days.

Infiltration can be used to:

- Partially or wholly manage the first one inch of rainfall on-site – see **Table IN-1**.
- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs; See **Table IN-2**).
- Meet partial or full storage requirements for local stormwater detention standards
- In limited circumstances, retrofit existing developed areas.

As examples, the photo on the right shows an Infiltration Basin receiving stormwater runoff from an impervious area. The photo on the left illustrates a linear Infiltration Trench that treats parking lot runoff.

Figure IN-1 further illustrates typical Infiltration applications. **Figure IN-2** shows schematics of a typical Infiltration practice. **Tables IN-1 and IN-2** describe Infiltration design parameters and associated volume reduction and pollutant removal performance rates. **Table IN-3** is a design checklist to help guide the design process for Infiltration practices.

IN-1.1. Planning This Practice

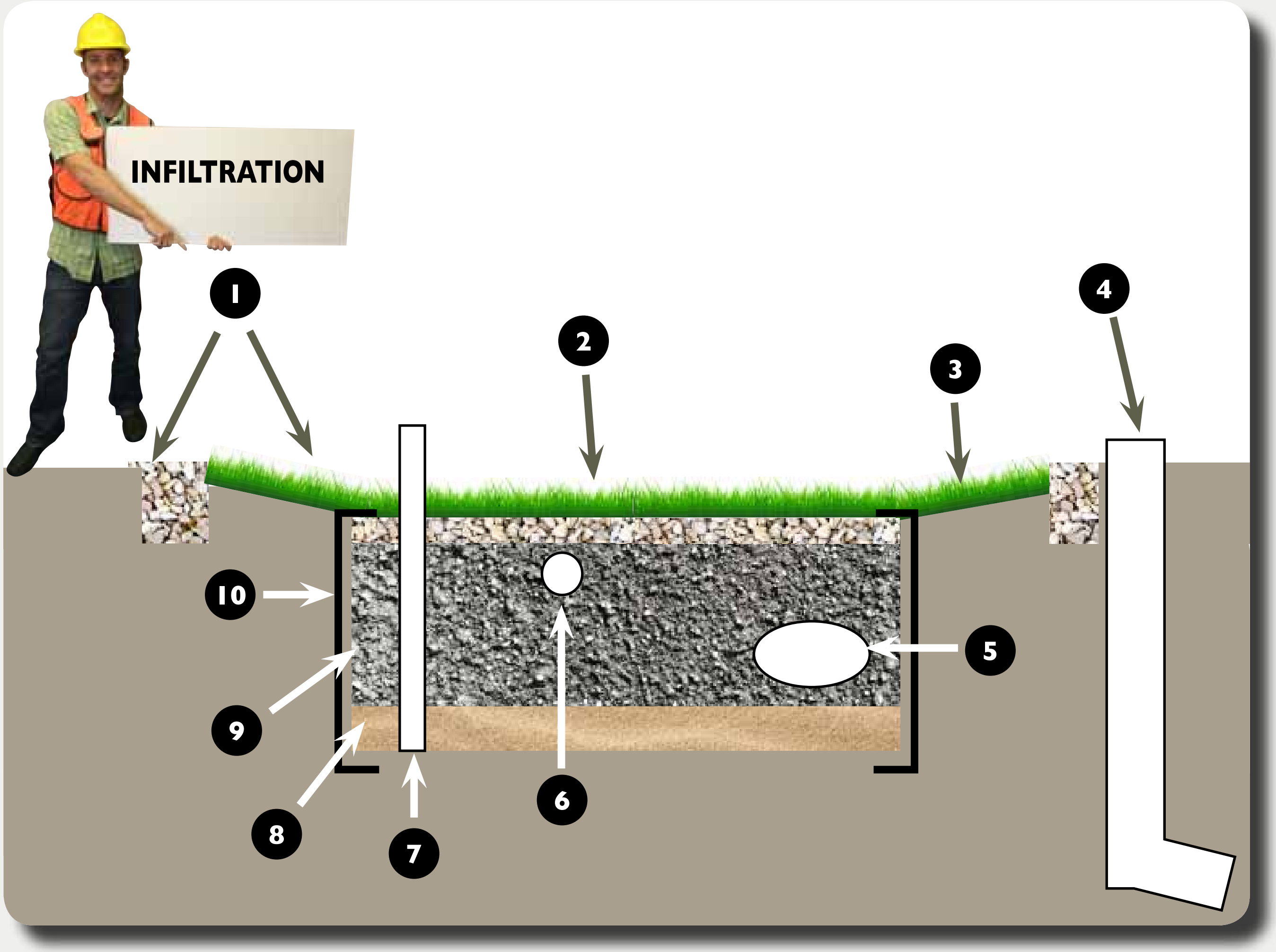
Figure IN-1. Typical Applications for Infiltration Practices

Edge of Parking Lot

In Median Strip

To Treat Roof Runoff or Other Small Areas of Impervious Cover (Micro-Scale)

Figure IN-2. Schematic of a Typical Infiltration Practice



1. **Pretreatment stone diaphragm & grass filter strip (typ.)** – Section IN-4.2
2. **Surface Cover: river stone; optional grass cover**– Sections IN-4.9
3. **Side Slopes = 4:1 Max** – Section IN-4.7
4. **Overflow Structure for Larger Flows** – Section IN-4.3
5. **Additional Underground Storage (optional)** – Section IN-4.13
6. **Overdrain (optional)** – Section IN-4.12
7. **Observation well** – Section IN-4.11
8. **Sand layer = 6" Min.** – Section IN-4.10
9. **Stone reservoir layer (variable depth)** – Sections IN-4.1 & IN-4.8
10. **Filter Fabric (sides only)** – Section IN-4.14

IN-1.2. Infiltration Design Options & Performance

Table IN-1 describes the design options for Infiltration and its practice performance in terms of reducing the volume associated with one inch of rainfall on the site. There is only one design level for Infiltration practices. Table IN-2 summarizes pollutant removal performance values for Infiltration designs for the purposes of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans.

Table IN-1. Infiltration Design Levels: Descriptions & Performance

Design Level	Description	Applications	Performance[1]
One Design Level	Basic Design -- • At least two forms of pre-treatment (see Section IN-4.2) • Field-measured soil infiltration rate of 0.5 to 4.0 inches/hour (see Appendix B of the Manual)	Sites with soils that are suitable for Infiltration and where the soils can be protected as part of site design and through the construction process.	100% volume reduction for the Design Volume of the practice[2]

[1] Performance achieved toward reducing one inch of rainfall
[2] Design Volume includes the volume of water that can be stored temporarily within the stone reservoir and subsequently infiltrated within 48 hours. The Design Volume can be 100% of that needed to meet the 1-inch performance standard or some proportion of it when used in conjunction with other practices. See Section IN-4.1 for Infiltration sizing requirements

Table IN-2. Pollutant Removal Performance Values for Level 1 and 2 Design

Design Level	Total Suspended Solids (TSS)[1]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)[1]
One Design Level	TSS = 75%	TP = 63% TN = 57%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008).

IN-1.3. Infiltration Design Checklist

Table IN-3. Infiltration Design Checklist

CHECKLIST

This checklist will help the designer through the necessary design steps for Infiltration.

- ☐ Conduct a preliminary investigation of site soils using Natural Resources Conservation Service (NRCS) or other sources (e.g., septic tests) to see if soils may be suitable for infiltration – Section IN-3
- ☐ Investigate site designs and layouts that preserve the best infiltration soils for stormwater treatment and whether these soils can be protected during construction
- ☐ Complete Design Compliance Spreadsheet to plan and confirm required Target Treatment Volume, additional practices needed, and overall site compliance – Site Compliance Spreadsheet & **Chapter 3 of Manual**
- ☐ Check other feasibility criteria – Section IN-3
- ☐ Conduct field soil infiltration studies at the specific locations for Infiltration practices – Appendix B of the Manual (this step is critical and can be done at different times during the site planning process)
- ☐ Check Infiltration sizing guidance and make sure there is an adequate footprint (often split into multiple areas) on the site for Infiltration practices– Section IN-4.1
- ☐ Check design adaptations appropriate to the site – Section IN-6
- ☐ Design Infiltration in accordance with design criteria and typical details – Sections IN-2 & IN-4
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence notes

4.2.6. Infiltration (IN)

IN-2. Typical Details

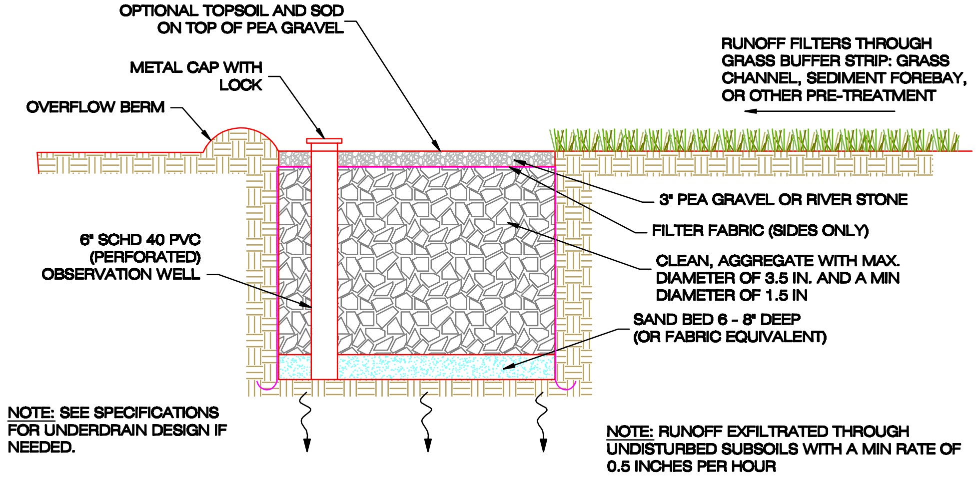


Figure IN-3. Typical Detail of Infiltration Trench

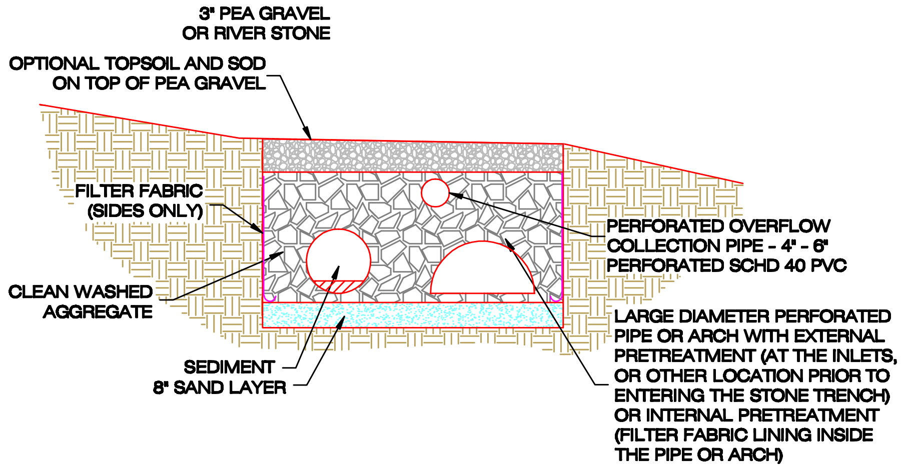


Figure IN-4. Infiltration Section with Supplemental Pipe Storage and Overflow Pipe

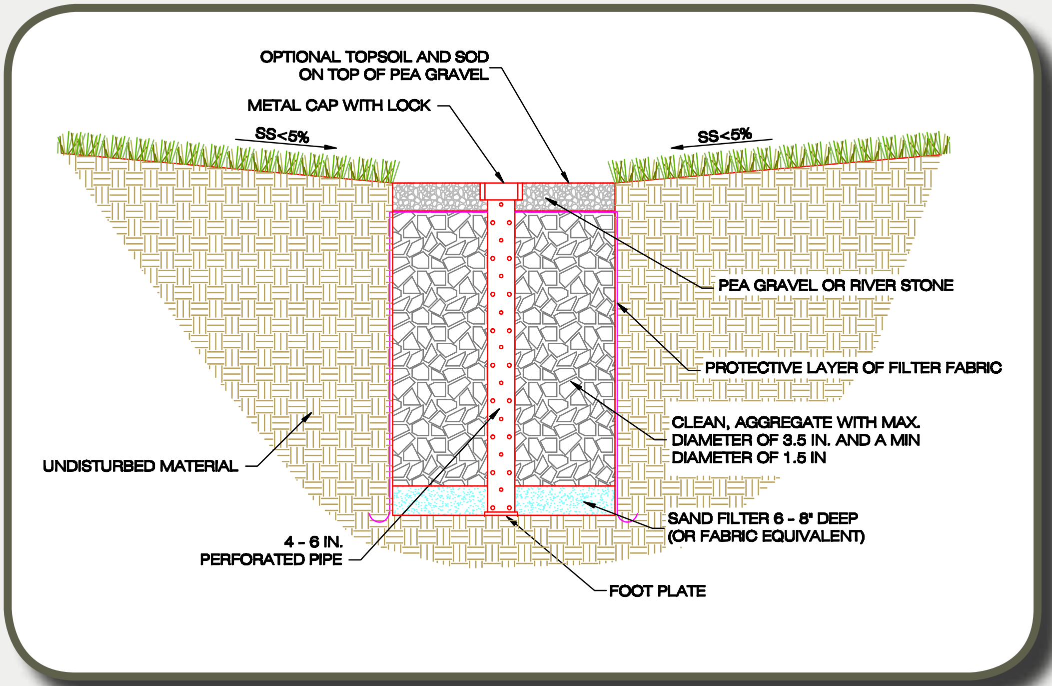


Figure IN-5. Typical detail of observation well

4.2.6. Infiltration (IN)

IN-3. Feasibility Criteria and Design Considerations

Infiltration practices have very high runoff reduction capabilities when sited and designed appropriately. Designers should evaluate the range of soil properties during initial site layout and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. In particular, areas of Hydrologic Soil Group (HSG) A or B soils shown on NRCS soil surveys should be considered as primary locations for Infiltration practices. Additional information about soil and infiltration are described in more detail later in this section. Key constraints with Infiltration include the following:

Site Topography. Infiltration should be located on relatively flat areas of sites. Practices are best applied when the grade of the area immediately adjacent to the Infiltration practice (within approximately 15 to 20 feet) is greater than 1% and less than 5%. For sites with steep grades, Infiltration should be split into multiple cells with adequate conveyance between the cells to take advantage of relatively flat areas. Unless slope stability calculations demonstrate otherwise, Infiltration practices should be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20%.

Available Hydraulic Head. Two or more feet of head may be needed to promote flow through Infiltration practices.

Minimum Depth to Water Table or Bedrock. A minimum vertical distance of 2 feet must be provided between the bottom of the Infiltration practice and the seasonal high water table or bedrock layer.

Soils. Native soils in proposed Infiltration areas must have a minimum field-measured infiltration rate of 0.5 inches per hour (typically HSG A and B soils meet this criterion). Initially, soil infiltration rates can be estimated from NRCS soil data, but designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix B of the Manual. Native soils must have silt/clay content less than 40% and clay content less than 20%. Soils investigation must be performed by a qualified soil scientist or geotechnical engineer. Soil boring locations should correspond to the location of the proposed Infiltration device, and should have a minimum of one boring for every 50 feet in length of the Infiltration practice. Infiltration measurements must be taken at and below the proposed invert elevation of Infiltration practices.

Infiltration Design Must Be Considered Early in Site Planning. Soils Intended for Infiltration Must Be Preserved in the Site Design

Early site planning should identify the best soils for Infiltration, and the site design should set these aside for Infiltration practice locations. The site and utility plan and erosion and sediment control plan should identify how the soils will be protected during construction to avoid disturbance and compaction.

Sites that have been previously graded or disturbed do not typically retain their original soil permeability due to compaction. Therefore, such sites are often not good candidates for Infiltration practices unless the geotechnical investigation shows that the soil infiltration rate exceeds 0.5 in/hr.

Contributing Drainage Area. The maximum contributing drainage area (CDA) to an individual Infiltration practice should be less than 2 acres, although smaller CDAs are recommended. The CDA should be as close to 100% impervious as possible. Micro-scale Infiltration practices can also be designed for individual rooftops or other small areas of impervious cover. The design, pretreatment and maintenance requirements will differ depending on the size of the Infiltration practice.

Hotspot Land Uses. Infiltration practices are not intended to treat sites with high sediment or trash/debris loads, because such loads will cause the practice to clog and fail. Infiltration practices should be avoided at potential stormwater hotspots that pose a risk of groundwater contamination.

For a list of potential stormwater hotspots, please consult **Chapter 5** of the Manual.

Floodplains. Infiltration practices should be constructed outside the limits of the 100-year floodplain, unless a waiver is obtained from the local authority.

No Irrigation or Baseflow. The planned Infiltration practice should not receive baseflow, irrigation water, chlorinated wash-water or other such non-stormwater flows.

Setbacks. Infiltration practices should not be hydraulically connected to structure foundations or pavement, in order to avoid harmful seepage. Setbacks to structures vary based on the CDA of the Infiltration practice:

- 250 to 2,500 square feet = 5 feet if down-gradient from building; 25 feet if up-gradient.
- 2,500 to 20,000 square feet = 10 feet if down-gradient from building; 50 feet if up-gradient.
- 20,000 to 100,000 square feet = 25 feet if down-gradient from building; 100 feet if up-gradient

Proximity to Utilities. A minimum of 5 feet horizontal distance should be maintained between a utility line and Infiltration practice. No utility line shall be placed over, under or within an Infiltration practice. A minimum of 100 feet horizontal distance shall be maintained between a water supply well and an Infiltration practice.

Underground Injection Permits for Class V Injection Wells

In order for an Infiltration practice to avoid classification as a Class V injection well, which is subject to regulation under the Underground Injection Control (UIC) program, the practice must generally be wider than the practice is deep. If an Infiltration practice is "deeper than its widest surface dimension," or if it includes an underground distribution system then it will likely be considered a Class V injection well. Class V injection wells are subject to permit approval by West Virginia Department of Environmental Protection (WVDEP).

IN-4. Design Criteria

IN-4.1. Infiltration Sizing for Water Quality & Volume Reduction

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a best management practice (BMP) plan:

Target Treatment Volume (Tv) = Volume associated with managing 1" of rainfall based on the size and land cover of the CDA, as determined by the Design Compliance Spreadsheet. Any given BMP may treat the full Tv, or only part of it, if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on temporary storage in the stone reservoir (for Infiltration practices), as prescribed in the BMP specification. Infiltration practices can often be part of a treatment train BMP design, with possible upgradient and downgradient practices. In these cases, the Dv of the Infiltration practice will be a subset of the overall Tv for the CDA. The sum of all Design Volumes in the Infiltration practice and other practices in the treatment train should equal the Tv.

See **Chapter 3** for more information on the runoff reduction design methodology.

For the purposes of this sizing section, the sizing relates to the Dv of the Infiltration practice being designed.

The proper approach for designing Infiltration practices is to avoid forcing a large amount of infiltration into a small area. Therefore, as stated in the text box above, individual Infiltration practices that are limited in size due to soil permeability and available space need not be sized to achieve the full 1-inch Target Treatment Volume (Tv) for the CDA, as long as other stormwater treatment practices are applied at the site to meet the remainder of the Tv.

Several equations are needed to size Infiltration practices. The first equation establishes the maximum underground reservoir depth of the Infiltration practice (**Equation IN-1**).

Equation IN-1. Maximum Underground Reservoir Depth for Infiltration Practices

$$d_{max} = \frac{1/2\, i \times t_d}{\eta_r}$$

Where:

dmax = maximum depth of the Infiltration practice (feet)
i = field-verified infiltration rate for the native soils (ft./day)
t_d = maximum drawn down time (normally 1.5 to 2 days) (day)
η_r = available porosity of the stone reservoir (assume 0.35)

This equation makes the following design assumptions:

- Conservative Infiltration Rates. For design purposes, the field-tested subgrade soil infiltration rate (i) is divided by 2 as a factor of safety to account for potential compaction during construction and to approximate long term infiltration rates. On-site infiltration investigations should always be conducted to establish the actual infiltration capacity of underlying soils, using the methods presented in Appendix B.
- Stone Layer Porosity. A porosity value of 0.35 shall be used in the design of stone reservoirs, although a larger value may be used if perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials are installed within the reservoir.
- Rapid Drawdown. Infiltration practices should be sized so that the target runoff reduction volume infiltrates within 36 hours to 48 hours, to prevent nuisance ponding conditions.

Designers should compare these results to the maximum allowable depths in **Table IN-4**, and use whichever value is less for subsequent design.

Table IN-4. Maximum Depth (in feet) for Underground Stone Reservoir

Mode of Entry	Scale of Infiltration: Contributing Drainage Area (CDA)		
	Micro Infiltration (CDA = 250 to 2,500 square feet)	Small Scale Infiltration (CDA = 2,500 to 20,000 square feet)	Conventional Infiltration (CDA = 20,000 to 100,000 square feet)
Underground Stone Reservoir	3.0	5.0	varies

Once the maximum depth is known, calculate the surface area needed for an Infiltration practice using **Equation IN-2**:

Equation IN-2. Underground Reservoir Surface Area for Infiltration Practices

$$SA = \frac{Design\ Volume}{(\eta_r \times d) + \left({}^{1}\!/_{2}\, i \times t_f\right)}$$

Where:

SA	=	Surface area (sq. ft.)
Design Volume	=	Volume (or portion of it) to be treated by Infiltration practice (see Design Compliance Spreadsheet)
η_r	=	available porosity of the stone reservoir (assume 0.35)
d	=	Infiltration depth (ft.) (maximum depends on the scale of infiltration and the results of Equation IN- 1)
i	=	field-verified infiltration rate for the native soils (ft./day)
t_f	=	Time to fill the Infiltration facility (days; typically 2 hours, or 0.083 days)

The Design Volume captured by the Infiltration practice is defined as the volume of water that is fully infiltrated through the practice with no overflow.

The Design Volume can be determined by rearranging **Equations IN-2** to yield **Equation IN-3**.

Equation IN-3. Design Volume Calculation for Underground Reservoir Surface Area for Infiltration Practices

$$Design\ Volume = SA\left[(\eta_r \times d) + \left({}^{1}\!/_{2}\, i \times t_f\right)\right]$$

Infiltration practices can also be designed to address, in whole or in part, the detention storage needed to comply with local stormwater detention requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer, any perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials installed within the reservoir, expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

IN-4.2. Pretreatment

Pre-Treatment is Essential

Every Infiltration system must have at least two pretreatment mechanisms to protect the long term integrity of the infiltration rate and to achieve the runoff reduction rate assigned in Table IN-1.

One of the following techniques must be installed to pretreat the inflow in every Infiltration facility:

- grass filter strip (minimum 20 feet and only if sheet flow is established and maintained)
- grass channel
- forebay (minimum 25% of the Design Volume)
- gravel diaphragm (minimum 1 foot deep and 2 feet wide and only if sheet flow is established and maintained)
- sand filter cell (see **Specification 4.2.10, Filtration**)

For pre-treatment structures at the edge of pavement (e.g., grass filter strips, gravel diaphragms, flow splitters), it is important that there be a 2 to 4 inch drop from the edge of pavement to the top of the grass or stone in the pre-treatment structure. This is to prevent accumulation of debris and subsequent clogging at the point where runoff is designed to enter the pre-treatment structure (see **Figure IN-6**).

If the infiltration practice serves a CDA greater than 20,000 square feet, a forebay or sand filter cell must be used for pre-treatment (see **Figure IN-7**). The forebay or sand filter cell must have a storage volume equivalent to at least 25% of the total Design Volume for the practice. This volume should be increased to 50% of the Design Volume if the infiltration rate for the underlying soils is greater than 2.0 inches per hour.

Designers should ensure that exit velocities from the pretreatment chamber are not erosive (e.g., less than 6 feet/second for the 15-year storm) and flow from the pretreatment chamber should be evenly distributed across the width of the practice (e.g., using a level spreader or energy dissipater).

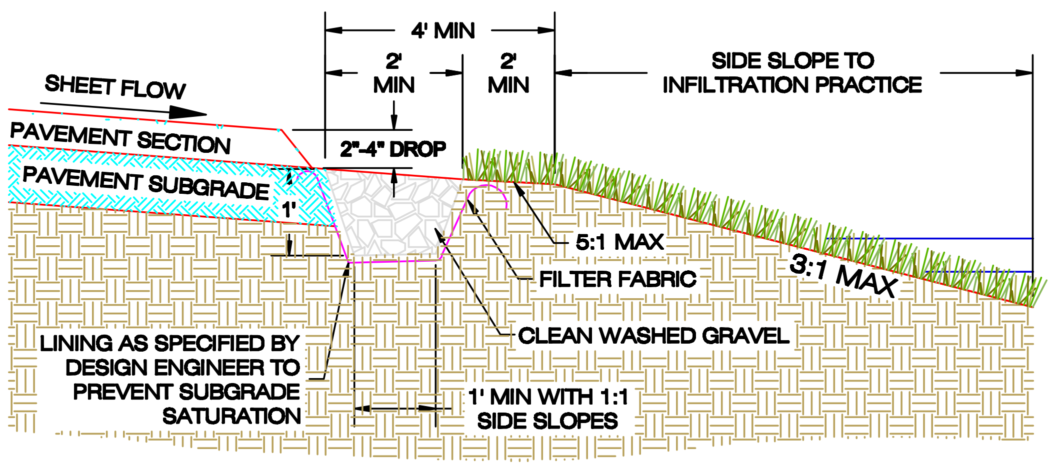


Figure IN-6. Typical Detail for Pre-Treatment at Pavement Edge – A 2 to 4 inch drop from the pavement to the top of stone helps to prevent clogging.

Figure IN-7. Examples of pretreatment forebay (left) and sand filter cell (right)

IN-4.3. Conveyance and Overflow

There are two basic design approaches for conveying runoff into, through, and around Infiltration practices.

1. **Off-line:** Flow is split or diverted so that only the design storm or design flow enters the Infiltration area. Larger flows by-pass the Infiltration bed. Off-line designs can be accomplished by establishing a maximum ponding depth (at which point higher flows are diverted) or a flow diversion or flow splitter at or upgradient of the inlet. Off-line designs are strongly recommended for Infiltration practices with a CDA larger than 0.5 acres so that flows to do not overwhelm or damage the Infiltration area.

2. **On-line:** All runoff from the drainage area flows into the practice. Flows that exceed the design capacity exit the practice via an overflow structure or weir. The following criteria apply to overflow structures:
   - An overflow shall be provided within the practice to pass storms greater than the design storm storage to a stabilized conveyance or storm sewer system. The overflow structure elevation should be above the Infiltration surface so that flows do not bypass the Infiltration treatment.
   - The overflow should be controlled so that velocities are non-erosive at the outlet point (i.e., to prevent downstream erosion).
   - The overflow capture device should be scaled to the application – this may be a landscape grate or yard inlet for small practices or a commercial-type structure for larger installations.

See Section BR-4.4 in Specification 4.2.3, Bioretention for more details and examples of off-line and on-line designs.

It should be noted that both types of design approaches require attention to safe conveyance of larger flows in adequate conveyances and with adequate freeboard to a receiving waterbody. Drainage design should be based on expected peak discharges assuming that upstream practices may fail and/or provide marginal storage during larger events. These concerns should be addressed in a plan's overall drainage approach.

IN-4.4. Design Geometry

Where possible, Infiltration practices should be designed to be wider than they are deep, to avoid classification as a Class V injection well (see Section IN-3).

IN-4.5. Practice Slope

The bottom of an Infiltration practice should be flat (i.e., 0% longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater.

IN-4.6. Ponding Depth

The maximum vertical depth over an Infiltration practice is 12 inches.

IN-4.7. Side Slopes

The side-slopes should be no steeper than 4H:1V.

IN-4.8. Stone Layer

Stone layers must consist of clean, washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches.

IN-4.9. Surface Stone/Surface Cover

A 3-inch layer of clean, washed river stone or No. 8 or 89 stone should be installed over the stone layer.

As an option, designers may choose to install a layer of topsoil and grass above the Infiltration practice (e.g., on top of the No. 8 or 89 stone; see **Figure IN-8**).

IN-4.10. Trench Bottom

To protect the bottom of an Infiltration Trench from intrusion by underlying soils, a sand layer must be used. The underlying native soils should be separated from the stone layer by a 6 to 8 inch layer of coarse sand (e.g., ASTM C 33, 0.02-0.04 inch).

IN-4.11. Observation Well

Infiltration practices should include an observation well, consisting of an anchored 6-inch diameter perforated PVC pipe fitted with a lockable cap installed flush with the ground surface, to facilitate periodic inspection and maintenance. An observation should be installed for each 50 linear feet of the practice.

Figure IN-8. Example of an Infiltration Trench with Surface Cover

IN-4.12. Overdrain

An optional overflow collection pipe (overdrain) can be installed in the stone layer to convey collected runoff from larger storm events to a downstream conveyance system.

IN-4.13. Underground Storage Layer (optional)

Runoff is stored in the voids of the stones, and infiltrates into the underlying soil matrix. Perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials can be used in conjunction with the stone to increase the available temporary underground storage. In some instances, a combination of filtration and infiltration cells can be installed in the floor of a dry extended detention pond, provided that there is adequate pretreatment and the ponding depth above the Infiltration bed is limited to 1 foot.

IN-4.14. Filter Fabric

Woven, monofilament filter fabric may be placed on the side slopes of the infiltration practice. In no case shall filter fabric be used along the bottom surface of the practice.

IN-4.15. Infiltration Landscaping Criteria

Infiltration practices can be effectively integrated into the site plan and aesthetically designed with adjacent native landscaping or turf cover, subject to the following additional design considerations:

- Infiltration practices should NEVER be installed until all up-gradient construction is completed AND pervious areas are stabilized with dense and healthy vegetation.
- Vegetation associated with the Infiltration practice buffers should be regularly mowed and maintained to keep organic matter out of the Infiltration device and maintain enough vegetation to prevent soil erosion from occurring.

4.2.6. Infiltration (IN)

IN-5. Materials Specifications

Table IN-5 provides materials specifications for Infiltration practices.

Table IN-5. Infiltration Material Specifications

Material	Specification	Notes
Surface Layer (optional)	Topsoil and grass layer	
Surface Stone	3-inch layer of river stone or pea gravel.	This provides an attractive surface cover that can suppress weed growth.
Stone Layer	Clean, aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches.	

Material	Specification	Notes
Observation Well	Vertical 6-inch Schedule 40 PVC perforated pipe, with a lockable cap and anchor plate.	Install one per 50 feet of length of Infiltration practice.
Overflow collection pipe (optional)	Use 4-inch or 6-inch rigid schedule 40 PVC pipe, with 3/8" perforations at 6 inches on center, with each perforated overflow pipe installed at a slope of 1% for the length of the Infiltration practice.	
Trench Bottom	6 to 8 inch sand layer (e.g., ASTM C 33, 0.02-0.04 inch)	
Filter Fabric (sides only)	Woven, monofilament filter fabric may be placed only on the side slopes.	
Buffer Vegetation	Keep adjacent vegetation from forming an overhead canopy above Infiltration practices, in order to keep leaf litter, fruits and other vegetative material from clogging the stone.	

4.2.6. Infiltration (IN)

IN-6. Design Adaptations

IN-6.1. Karst Terrain

Karst regions are found in much of the Ridge and Valley and Panhandle. Karst complicates both land development and stormwater design. Large-scale Infiltration practices (with CDAs larger than 20,000 square feet) **should not be used** in karst regions due to concerns about sinkhole formation and groundwater contamination. Micro- or small-scale Infiltration areas are permissible, and the following design modifications should be considered (CSN, 2009):

- The surface area of the Infiltration practice should be maximized vis-à-vis the depth. It is recommended that the stone reservoir layer be 24 inches or less.
- Soil borings and/or geotechnical studies must indicate at least three feet of vertical separation exist between the bottom invert of the Infiltration practice and the karst bedrock layer.
- In many cases, Bioretention is a preferred stormwater alternative to Infiltration in karst areas.
- Infiltration is prohibited if the CDA is classified as a severe stormwater hotspot (see **Chapter 5** of the Manual).

IN-6.2. Steep Slopes

Forcing conventional Infiltration practices in steep terrain can be problematic with respect to slope stability, excessive hydraulic gradients and sediment delivery. Unless slope stability calculations demonstrate otherwise, it is generally recommended that Infiltration practices should be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20%. Micro-scale and small-scale Infiltration can work well, as long as their smaller up-gradient and down-gradient building setbacks are satisfied.

IN-6.3. Cold Climate and Winter Performance

Infiltration practices can be designed to withstand more moderate winter conditions. The main problem is caused by ice forming in the voids or the subsoils below the practice, which may briefly result in nuisance flooding when spring melting occurs. The following design adjustments are recommended for Infiltration practices installed at higher elevations:

- The bottom of the practice should extend below the frost line.
- Infiltration practices are not recommended in the right-of-way immediately adjacent to roadsides that are heavily sanded and/or salted in the winter months (to prevent movement of chlorides into groundwater and prevent clogging by road sand).
- Pre-treatment measures can be oversized to account for the additional sediment load caused by road sanding (up to 40% of the Design Volume).
- Infiltration practices must be set back at least 25 feet from roadways to prevent potential frost heaving of the road pavement.

IN-6.4. Stormwater Retrofitting

As a stand-alone practice, Infiltration is likely to be used rarely in a retrofit context due to the disturbed soils in many developed areas. Adequate soil and geotechnical tests must be conducted to verify that the underlying soil is suitable for Infiltration and that infiltrated water will not cause problems for existing building foundations, road sections, and other infrastructure elements. In cases where this can be verified, Infiltration may be a cost-effective retrofit practice.

For more information on retrofitting, see the Center for Watershed Protection's manual, ***Urban Stormwater Retrofit Practices*** (Schueler et al., 2007).

4.2.6. Infiltration (IN)

IN-7. Construction & Installation

IN-7.1. Infiltration Construction Sequence

Infiltration Construction Sequence

Infiltration practices are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the practice. In addition, heavy construction can result in compaction of the soil, which can then reduce the soil's infiltration rate. For this reason, a careful construction sequence needs to be followed. Ideally, the Infiltration practice should remain outside of the limit of disturbance during construction.

During site construction, the following steps are absolutely critical:

- Avoid excessive compaction by preventing construction equipment and vehicles from traveling over the proposed location of the Infiltration practice.
- Keep the Infiltration practice "off-line" until construction is complete. Prevent sediment from entering the Infiltration site by using super silt fence, diversion berms or other means. In the erosion and sediment control plan, indicate the earliest time at which stormwater runoff may be directed to an Infiltration practice. The erosion and sediment control plan must also indicate the specific methods to be used to temporarily keep runoff from the Infiltration site.
- Infiltration practice locations should never serve as the sites for temporary sediment control devices (e.g., sediment traps, etc.) during construction.
- Upland drainage areas need to be completely stabilized with a thick layer of vegetation prior to commencing excavation for an Infiltration practice.

IN-7.2. Infiltration Installation

The actual installation of an Infiltration practice is done using the following steps:

Step 1. Excavate the Infiltration practice to the design dimensions from the side, using a backhoe or excavator. The floor of the pit should be completely level, but equipment should be kept off the floor area to prevent soil compaction.

Step 2. Install filter fabric on the trench sides. Large tree roots should be trimmed flush with the sides of Infiltration Trenches to prevent puncturing or tearing of the filter fabric during subsequent installation procedures. When laying out the filter fabric, the width should include sufficient material to compensate for perimeter irregularities in the trench and for a 6-inch minimum overlap at the top of the trench. The filter fabric itself should be tucked under the sand layer on the bottom of the Infiltration Trench. Stones or other anchoring objects should be placed on the fabric at the trench sides, to keep the trench open during windy periods. Voids may occur between the fabric and the excavated sides of a trench. Natural soils should be placed in all voids, to ensure the fabric conforms smoothly to the sides of excavation.

Step 3. Scarify the bottom of the Infiltration practice, and spread 6 inches of sand on the bottom as a filter layer.

Step 4. Anchor the observation well(s), and add stone to the practice in 1-foot lifts.

Step 5. Use sod, where applicable, to establish a dense turf cover for at least 10 feet around the sides of the Infiltration practice, to reduce erosion and sloughing. Sod should not be used over the Infiltration bed itself. For designs that call for a turf cover over the Infiltration bed, seeding and use of a biodegradable erosion control matting are good alternatives for establishing the turf cover.

Step 6. Conduct the final construction inspection, then log the GPS coordinates for each Infiltration facility and submit them for entry into the local maintenance tracking database.

An example construction phase inspection checklist is available in Appendix A of the Manual.

4.2.6. Infiltration (IN)

IN-8. Maintenance Criteria

Maintenance is a crucial element that ensures the long-term performance of Infiltration practices. The most frequently cited maintenance problem for Infiltration practices is clogging of the stone by organic matter and sediment. The following design features can minimize the risk of clogging:

Stabilized CDA. Infiltration systems may not receive runoff until the entire CDA has been completely stabilized.

No Filter Fabric on Bottom. Do not install geotextile or filter fabric along the bottom of Infiltration practices. Experience has shown that these fabrics are prone to clogging.

Direct Maintenance Access. Infiltration systems must be covered by a drainage easement to allow inspection and maintenance. Access must be provided to allow personnel and construction equipment to perform non-routine maintenance tasks, such as practice reconstruction or rehabilitation. While a turf cover is permissible for small-scale Infiltration practices, the surface must never be covered by an impermeable material, such as asphalt or concrete.

Maintenance agreements and plans must be executed between the owner and the local authority. The agreements will specify the property owner's primary maintenance responsibilities and authorize local agency staff to access the property for inspection or corrective action in the event that proper maintenance is not performed.

Effective long-term operation of Infiltration practices requires a dedicated and routine maintenance inspection schedule with clear guidelines and schedules, as shown in **Table IN-6** below. Where possible, facility maintenance should be integrated into routine landscaping maintenance tasks.

Table IN-6. Recommended Maintenance Tasks for Infiltration Practices

Maintenance Tasks	Frequency
• Replace pea gravel/topsoil and top surface filter fabric (when clogged). • Mow grass surface over (if applicable) as necessary and remove the clippings.	As needed
• Ensure that the CDA, inlets, and facility surface are clear of debris. • Ensure that the CDA is stabilized. Perform spot-reseeding if where needed. • Remove sediment and oil/grease from inlets, pre-treatment devices, flow diversion structures, and overflow structures. • Repair undercut and eroded areas at inflow and outflow structures.	Quarterly
• Check observation wells 3 days after a storm event in excess of 1/2 inch in depth. Standing water observed in the well after three days is a clear indication of clogging. • Inspect pre-treatment devices and diversion structures for sediment build-up and structural damage. • Remove trees that start to grow in the vicinity of the Infiltration facility that may drop leaf litter, fruits and other vegetative materials that could clog the Infiltration device.	Semi-annual inspection
• Clean out accumulated sediments from the pre-treatment cell.	Annually

It is highly recommended that annual site inspections be performed for Infiltration practices to ensure the practice performance and longevity. An example maintenance inspection checklist for Infiltration systems can be found in **Appendix A of the Manual**.

REFERENCES

Chesapeake Stormwater Network. 2009. CSN Technical Bulletin No. 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed, Version 2.0.

Hirschman, D., Collins, K., and T. Schueler. 2008. Technical Memorandum: The Runoff Reduction Method. Center for Watershed Protection and Chesapeake Stormwater Network. Ellicott City, MD.

Schueler, T., D. Hirschman, M. Novotney, and J. Zielinski. 2007. Urban Stormwater Retrofit Practices, Version 1.0, Urban Subwatershed Restoration Manual No. 3.

U.S. Environmental Protection Agency. 2008. Memorandum: Clarification of which stormwater infiltration practices/technologies have the potential to be regulated as "Class V" wells by the Underground Injection Control Program. From: Linda Boornazian, Director, Water Permits Division (MC 4203M); Steve Heare, Director, Drinking Water Protection Division (MC 4606M).

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RSC-1. Introduction

Source: Biohabitats, Inc.

Regenerative Stormwater Conveyance (RSC) is an innovative approach to provide stormwater treatment, infiltration, and conveyance within one system. It has been used as an ecosystem restoration practice for eroded or degraded outfalls and drainage channels. RSC utilizes a series of shallow aquatic pools, riffle weir grade controls, native vegetation and underlying sand and woodchip beds to treat, detain, and convey storm flow. It can be used in places where grades make traditional stormwater practices difficult to implement. RSC Systems combine features and treatment benefits of Swales, Infiltration, Filtering and Wetland practices. In addition, they are designed to convey flows associated with extreme floods (i.e., 100-year storm) in a non-erosive manner, which results in a reduction of channel erosion impacts commonly encountered at conventional stormwater outfalls and headwater stream channels.

RSC can be used to:

- Manage the first one inch of rainfall on-site (See **Table RSC-1**)
- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs; See **Table RSC-2**).
- Meet partial or full storage requirements for local stormwater detention standards
- Retrofit existing developed areas, especially areas with eroded and degraded (entrenched) outfalls, ditches, and ephemeral or intermittent gullies that discharge to waterbodies

RSC can be blended into the landscape design for many sites. As an example, the photo above shows a RSC System at an outfall in Anne Arundel County, Maryland (Source: J. Berg).

Figure RSC-1 shows before and after photographs of RSC designs used to restore and repair existing incised and eroding outfalls and channels. **Figure RSC-2** is a schematic profile of the typical RSC System.

RSC-1.1. Planning This Practice

Before (Left): Eroded outfall. After (Right): Outfall restored using RSC design.

Before (Left): Incised and eroding channel. After (Right): RSC design reconnects channel to floodplain.

Figure RSC-1. Before and after photos of Regenerative Stormwater Conveyance retrofits. Source: Biohabitats, Inc

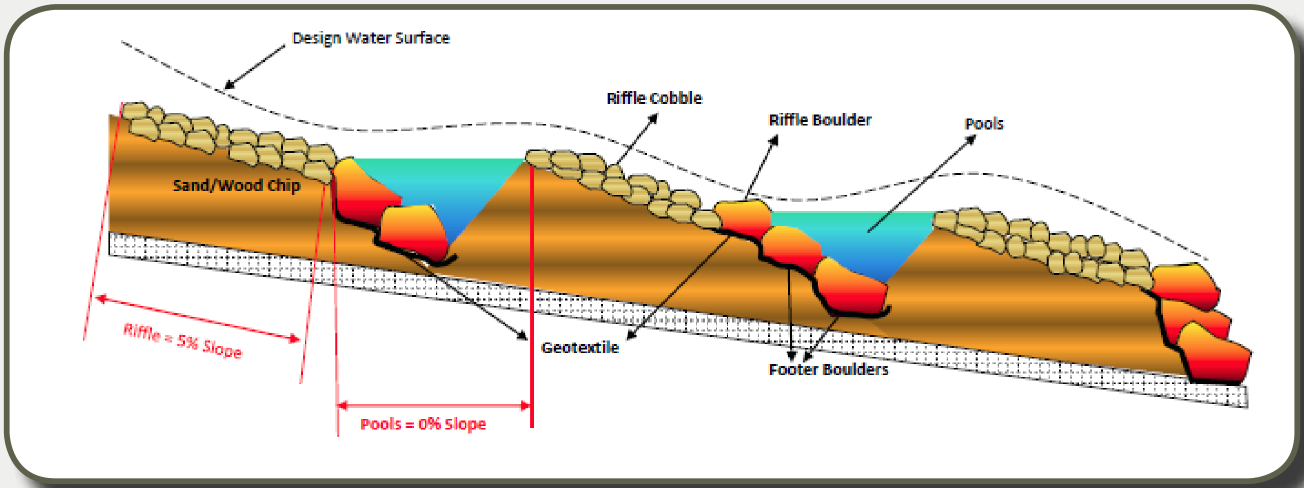

Figure RSC-2. Schematic Profile for Regenerative Stormwater Conveyance System (Source: Anne Arundel County, 2011)

RSC-1.2. Regenerative Stormwater Conveyance System Design Options & Performance

Table RSC-1 describes the RSC performance in terms of reducing the volume associated with one inch of rainfall on the site. **Table RSC-2** summarizes pollutant removal performance values for RSC. This is for the purpose of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans. Since RSC is a relatively new practice without a long monitoring record, these rates are based on the performance of a Level 2 Water Quality Swale (see **Specification 4.3.2.A Water Quality Swale**). These rates can be considered provisional until more monitoring data specific to RSC becomes available.

Table RSC-1. RSC Descriptions & Performance (based on Level 2 Water Quality Swale)

Description	Applications	Performance[1]
RSC generally designed according to Anne Arundel County (2011)	Sites where topography, slopes, or other site constraints suggest that treatment be provided in the conveyance system. This may be particularly relevant to redevelopment sites and/or retrofits with eroded and degraded outfalls, ditches, or ephemeral or intermittent entrenched gullies. In these cases, the RSC can also serve as an ecosystem restoration project.	100% volume reduction for the Design Volume of the practice[2]

[1]Performance achieved toward reducing one inch of rainfall
[1] Design Volume includes storage within the pools and within the sand/woodchip bed in accordance with the design methods in Section RSC-4 of this specification. The Design Volume can be 100% of that needed to meet the 1-inch performance standard or some proportion of it when used in conjunction with other practices.

Table RSC-2. Pollutant Removal Performance Values for RSC (based on Level 2 Water Quality Swale)

TSS = 90%	TP = 76% TN = 74%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008).

RSC-1.3. Regenerative Stormwater Conveyance System Design Checklist

Table RSC-3. RSC Design Checklist

CHECKLIST

This checklist will help the designer with the necessary design steps for RSC Systems.

- ☐ Assess site conditions to determine applicability of RSC. It is best used to restore ecological functions to an existing eroded ditch, outfall, channel, or ephemeral or intermittent stream. Check with the local stormwater authority to ensure that RSC is applicable to the particular site.
- ☐ The design process in Section RSC-4 is iterative. Make sure there is a large enough footprint on the site to accommodate an RSC System with enough storage. Use the Design Compliance Spreadsheet to calculate the Target Treatment Volume (Tv) for the drainage area, and then compare to the storage provided. Upgradient or downgradient runoff reduction practices can be used if the RSC System does not provide the total Tv storage.
- ☐ Complete the design process in Section RSC-4, including the design checklist in Section RSC-4.2. It is highly recommended that designers consult the resources provided in Anne Arundel County (2011) or the latest design reference for RSC.
- ☐ Check design adaptations appropriate to the site – Section RSC-6.
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence notes.

RSC-2. Typical Details

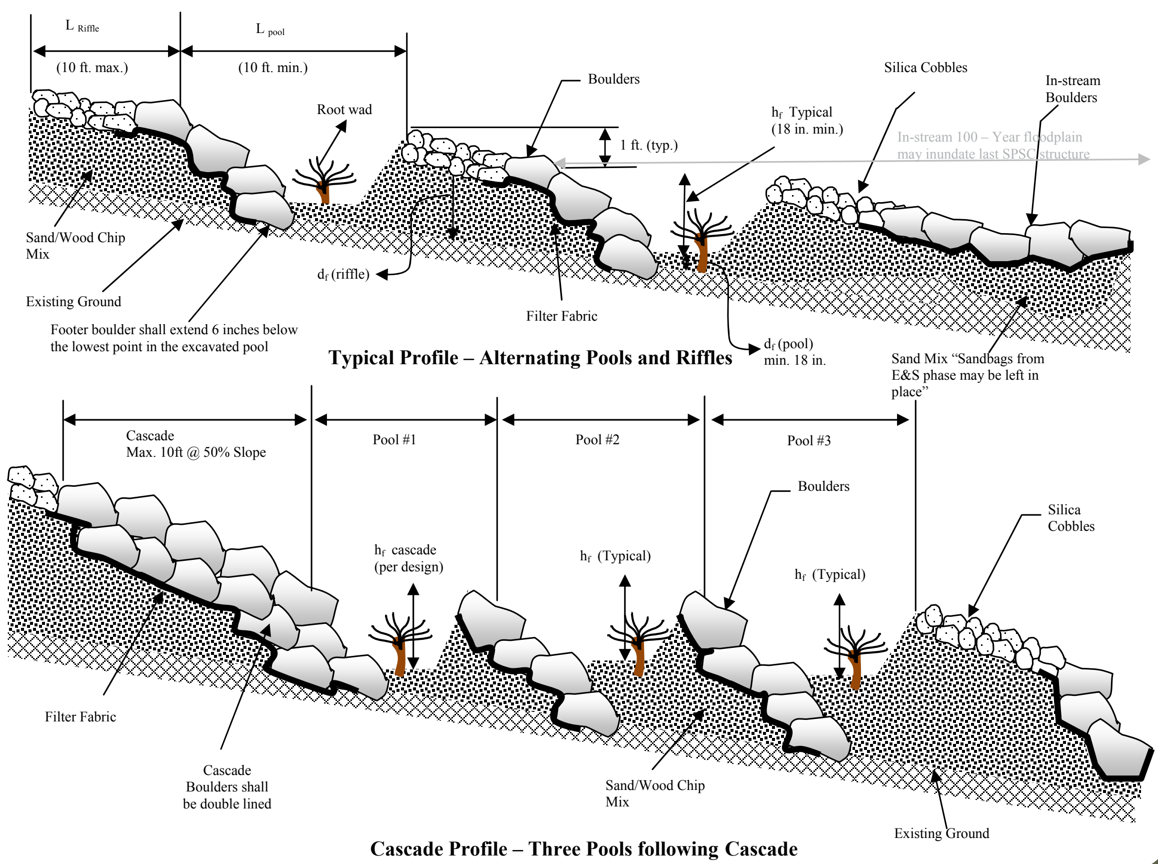

Figure RSC-3. Typical Profile of Alternating Pools and Riffles (top) and Three Pools following Cascade (bottom) (Source: Anne Arundel County, 2011).

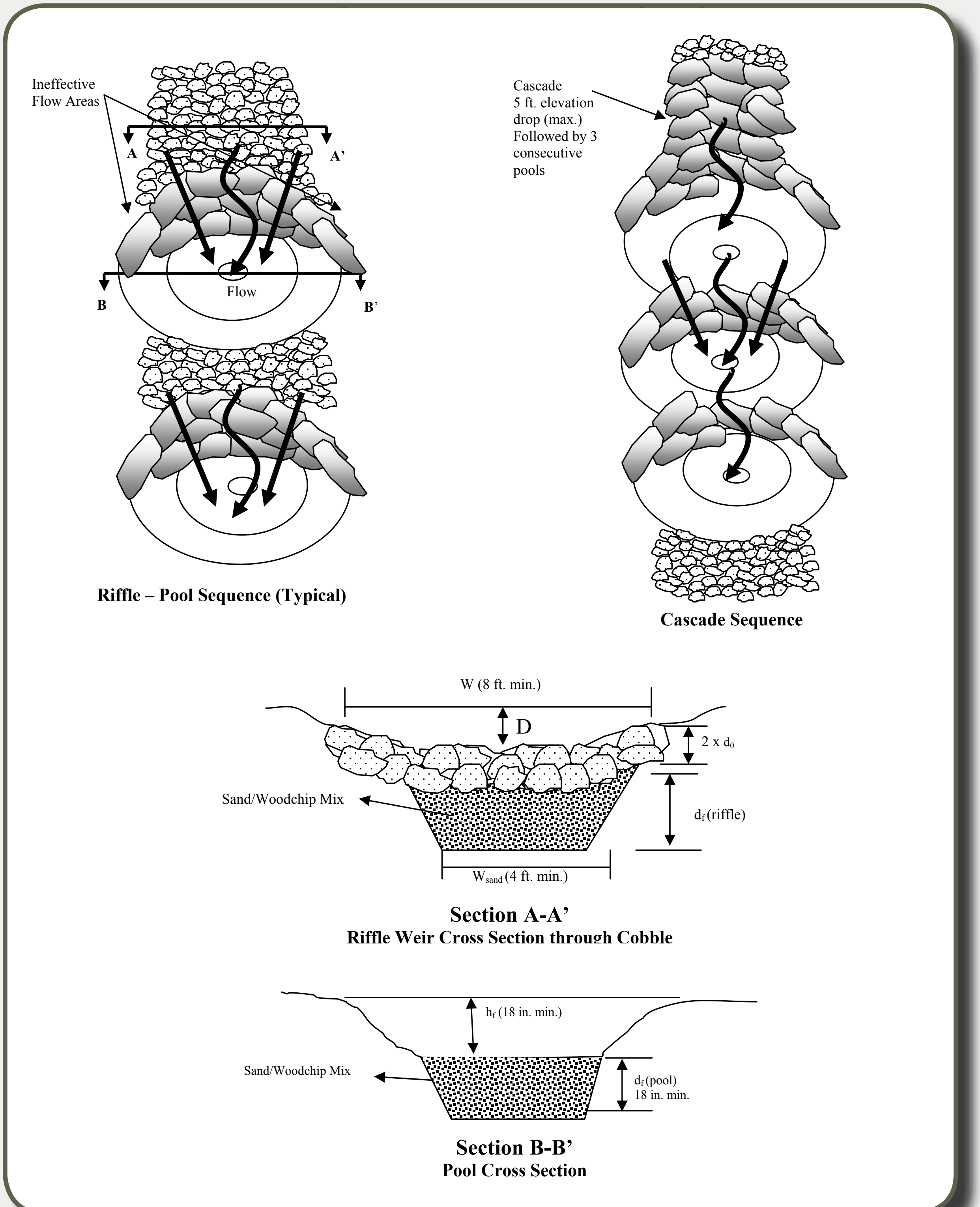

Figure RSC-4. Typical Plan View and Sections for Alternating Pools and Riffles (top left) and Cascades (top right) (Source: Anne Arundel County, 2011).

RSC-3. Feasibility Criteria and Design Considerations

Key design considerations for RSC Systems include the following. Designers are strongly encouraged to consult Anne Arundel County (2011) for additional design parameters.

Site Topography. RSC can be used to convey and treat stormwater down moderate to steep slopes. Ideally, the design is applied to existing drainage features (e.g., ditches, gullies) that have longitudinal slopes of 10% or less. However, the system can be adapted to steeper slopes by increasing the number and size of cobbles and boulders in the design.

Contributing Drainage Area. Typical drainage areas for RSC range from around 10 to 30 acres, and these tend to be highly impervious. While there is no official upper limit for the drainage area, designers may find that drainage areas greater than 50 acres will require the system size and materials (e.g., boulders) to increase to the point where cost and available space would become major factors. The percent impervious cover within the drainage area also plays a significant role, with highly impervious drainage areas leading to larger storage requirements.

Water Table. The main water table constraint is that storage above the ponding depth in the pools should be available for storm events and not inundated by seasonal groundwater. Pools should drain down to their design (ponding) levels within 72 hours from a storm event.

Soils and Underdrains. Soil conditions do not typically constrain the use of RSC since the storage is accounted for in the pools and within the sand/woodchip bed. As can be seen on the typical details, the entire system has a longitudinal slope, so underdrains (such as with Bioretention) are not needed.

Hotspot Land Uses. RSC should not be used to treat runoff from hotspot generating areas. However, the practice can treat "non-hotspot" parts of a site. For a list of potential stormwater hotspots, please consult Chapter 5 of the Manual.

Floodplains. One of the chief design considerations for RSC is how the step pool sequence ties into the downstream receiving channel, and whether that channel is incised or relatively stable. In this regard, some of the steps or pools may need to intersect the 100-year floodplain. In these cases, the designer should consider how the design should be modified to account for the flow velocities and inundation associated with the floodplain.

Proximity to Utilities. Interference with underground utilities should be avoided whenever possible, particularly water and sewer lines. Approval from the applicable utility company or agency is required if utility lines will run below or through the RSC System. Conflicts with water and sewer laterals (e.g., house connections) may be unavoidable, and the construction sequence must be altered, as necessary, to avoid impacts to existing service.

Additionally, designers should ensure that future tree canopy growth in an RSC System will not interfere with existing overhead utility lines.

Community Factors. RSC Systems can be designed as safe and aesthetically pleasing practices which, when incorporated into open space areas, can increase the natural value of a space.

Underground Injection Permits. RSC systems are generally not considered to be Class V injection wells subject to permits under the Underground Injection Control (UIC) Program (U.S. EPA, 2008). However, in certain cases the designer should confer with West Virginia Department of Environmental Protection (WVDEP) about the possible applicability of a UIC permit.

4.2.7. Regenerative Stormwater Conveyance System (RSC)

RSC-4. Design Criteria

RSC-4.1. Regenerative Stormwater Conveyance System Sizing

The design of RSC Systems is usually based upon providing safe and stable conveyance of the peak flow generated by the 100-year storm event. The Tv associated with the 1-inch performance standard will very likely be provided within this design framework. However, additional upgradient and/or downgradient runoff reduction practices may be needed in order to treat the full required Tv. If this is the case, the volume designed into the RSC System is called the Design Volume (Dv).

The procedure provided below is intended to assist in the design of a RSC System. Designers are strongly encouraged to consult Anne Arundel County (2011) or the latest design variation for RSC for additional design guidelines. The Anne Arundel County guidance can be found at: http://www.aacounty.org/DPW/Watershed/StepPoolStormConveyance.cfm

1. Using a topographic map with 1' contours, map the path of the RSC System. The path should be curvilinear and generally follow the shape/contours of the ravine or natural drainageway.
2. Measure the length of the path of the RSC System.
3. Measure the change in elevation that occurs along the path of the RSC System. The longitudinal slope should not exceed 5 percent. If the overall slope exceeds 5 percent, then one or more cascades can be designed into the system (see Step 5).
4. Using the results of Step 3, determine the required number of grade control structures and pools. The required number of grade control structures and pools is equal to the change in elevation that occurs along the path of the RSC System.
5. Using the following equation, determine the length of each of the grade control structures and pools. Grade control structures and pools will have an equal length along the path of the RSC System.

Equation RSC-1. Length of Grade Control Structures

Length of grade control structure = length of pool = [(Length of the path of the RSC System) / (Change in elevation that occurs along the path of the RSC System)] / 2

The length is the dimension of the grade control structures and pools that is parallel to the path of the RSC System.

NOTE: If the length of the grade control structures and pools is determined to be less than 10 feet, the system may require one or more cascades along its path. Cascades may have a longitudinal slope of up to 50 percent (2H:1V) and a maximum vertical drop of 5 feet. Cascades should be followed by 3 pools instead of 1 (see Figure **RSC-3**, bottom figure).

6. Determine the peak flow that is generated by the 100-year storm event.
7. Design the grade control structures, which should be parabolic in shape, to convey the peak flow generated by the 100-year storm event in a stable manner. Using the iterative process below, determine the width and depth of the grade control structures and the size of the material needed to construct them:
   a. Begin the design of the grade control structures using a cobble size (d0) of 6 inches. This cobble size should be generally available (e.g. Gabion Stone).
   b. Set the depth of the cobble material to 2.0 * d0. See **Figure RSC-5**.
   c. Determine a trial width (W) and depth (D) for the grade control structures. The width is the dimension perpendicular to the flow, and the depth is the maximum depth of the parabolic channel at that width (see **Figure RSC-5**). The width of the grade control structures should be: a) 10 times the depth of the grade control structures, and b) a minimum of 8 feet. The maximum width of the grade control structures should be 20 feet.

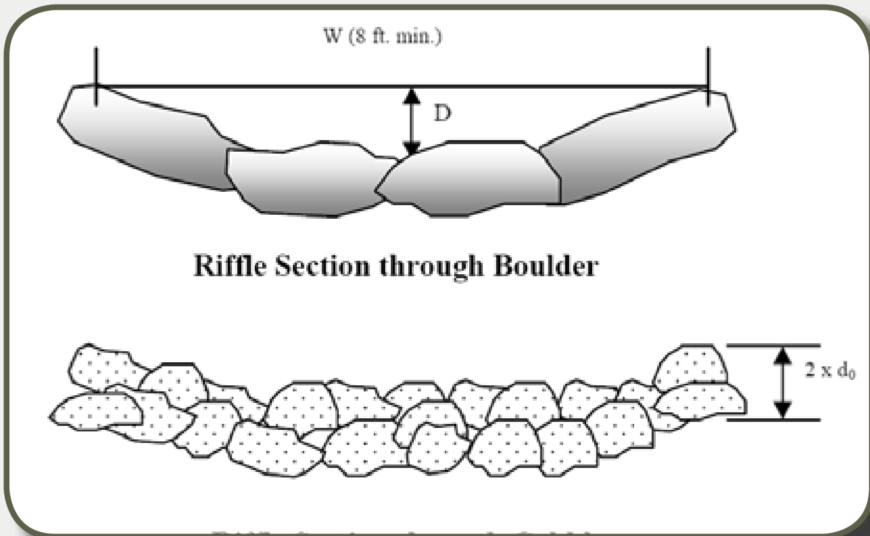

Figure RSC-5. Typical Width, Depth, and Depth of Stone for Grade Control (Riffle) Sections (Source: Anne Arundel County, 2011).

d. Determine the velocity of flow through the RSC System using Manning's formula for the velocity of uniform flow:

Equation RSC-2. Manning's Formula

$$V = \frac{1.49}{n\,(R_h)^{2/3}(S)^{1/2}}$$

Where:

V	=	velocity of flow (ft/s)
1.49	=	conversion factor
n	=	Manning's roughness coefficient
R_h	=	hydraulic radius (ft)
S	=	slope (ft/ft), in direction parallel to flow path

For a parabola:

$$R_h = \frac{2(DW^2)}{(3 \times W^2) + (8 \times D^2)}$$

Where:

W = top width of cross section (8 foot minimum)

D = depth of cross section

Manning's roughness coefficient (n) varies according to the depth of flow over the grade control structure and the size of cobble used to construct the grade control structure (MD NRCS, 2006):

Equation RSC-3. Manning's Roughness Coefficient

$$n = \frac{d^{1/6}}{[21.6 \times \log(d/d_0) + 14.0]}$$

Where:

n	=	Manning's roughness coefficient
d	=	depth of flow in the riffle channel associated with unmanaged 100-year flow conditions (ft)
d0	=	mean cobble size (ft)

In an RSC System, the depth of the flow over the grade control structures should be a maximum of 4 inches.

The flow velocity calculated using Manning's formula for the velocity of uniform flow must be less than the maximum allowable velocity for the cobble size that was selected in Step 7a. Maximum allowable velocities are illustrated in **Table RSC-4**. If the design velocity exceeds the maximum allowable velocity, select a larger cobble size and repeat Steps 7b-7d.

Table RSC-4. Maximum Allowable Velocity

Cobble size (d_0) (in)	Allowable velocity (ft/s)
4	5.8
5	6.4
6	6.9
7	7.4
8	7.9
9	8.4
10	8.8
11	9.2
12	9.6
15	10.4

8. Using the following equation, check to ensure that the RSC System is adequate to convey the peak flow generated by the 100-year storm event:

Equation RSC-4. Peak Flow

$$Q = V * A$$

Where:

V = low velocity through the RSC System (ft/s)

A = cross-sectional area (ft^2)

For a parabola:

$$A = 2/3 * D * W$$

Where:

W = top width of cross section

D = depth of cross section

The RSC System must be able to convey the peak flow generated by the 100-year storm event. If the peak flow generated by the 100-year exceeds the capacity of the system, increase the width of the grade control structures and repeat Steps 7d-8.

9. The Anne Arundel County RSC guidance (Anne Arundel County, 2011) provides additional guidance for ensuring subcritical flow conditions and non-erosive pool channel velocities (less than 4 feet/second). These computations require knowing the density of stone that will be used. Designers are encouraged to review these computations to ascertain if they think they may be relevant for a particular design.

10. Using the results of Step 7c, determine the width of the pools. The width of the pools is equal to the width of the grade control structures

11. Start with an assumed pool depth of 1.5 feet. The pool depth should be a minimum of 1.5 feet and a maximum of 3 feet.

12. Begin the design of the sand bed with a depth of 1.5 feet and a width of 4 feet. The sand bed should consist of a mixture of 80% sand and 20% wood chips and should run beneath the entire length of the RSC System. A 1 foot layer of bank run gravel should be placed beneath the sand bed to prevent piping and undermining of the sand bed. A 1 foot layer of bank run gravel should be placed over the surface of the sand bed to provide bedding for the grade control structures

13. Determine the Tv for the contributing drainage area (CDA) associated with the 1-inch performance standard using the Design Compliance Spreadsheet. The Tv is the total volume for the contributing drainage area. If there are other BMPs in series with the RSC System, then the RSC volume may account for only part of the Tv, with the sum of all BMP volumes equaling the Tv. The Dv is the volume designed into the RSC System in the pools and sand bed layer (see steps below).

14. Determine the storage provided in the shallow pools by multiplying the surface area of each pool by its depth and by a factor of 0.4, to account for the storage lost due to the side slopes of the pool, and then summing the results:

Equation RSC-5. Storage in Pools

$$V_{pool} = SA * d_{max} * 0.4$$

Where:

V_{pool}	=	storage volume provide in single pool (cubic feet)
SA	=	surface area of single pool (square feet)
d_{max}	=	maximum depth of pool (ft)
0.4	=	factor used to account for the storage lost due to the side slopes of each pool

NOTE: The storage volume provided in the pools may be more accurately computed using the contours shown on the grading plan after the design is completed.

15. Determine the storage volume provided in the sand bed beneath the RSC System. The storage volume provided by the sand bed storage can be estimated by multiplying the volume of the sand bed by the porosity of sand, typically 0.4:

Equation RSC-6. Storage in Sand Bed

$$V_{sand} = L_{sand} * W_{sand} * D_{sand} * 0.4$$

Where:

V_{sand}	=	storage volume provided in sand bed (cubic feet)
L_{sand}	=	length of sand bed (ft)
W_{sand}	=	width of sand bed (ft)
D_{sand}	=	depth of sand bed (ft)
0.4	=	porosity of sand

16. Add the storage volumes provided in the shallow pools and the sand bed (the design volume) and compare to the desired Dv and if various BMPs in the drainage area meet the target Tv. If an insufficient storage volume is provided in the pools and sand bed, the grade control structures, shallow pools and sand bed may be widened to provide additional storage. It is recommended that the maximum width of the sand bed should be 14 feet and the maximum width of the grade control structures and pools should be 20 feet.

17. If, after increasing the width of the grade control structures, pools and sand bed, the RSC System still does not provide the desired Dv, additional (or larger) stormwater management practices will need to be provided upstream or downstream of the system.

18. Using a topographic map with 1' contours, position the sand bed, choker stone, and bank run gravel layers along the path of the RSC System. Starting with the outlet pool, position each pool and grade control structure along the path of the RSC System. The outlet pool shall be placed at the downstream end of the system, at the lowest point in the project reach. The elevation of the top of the outlet pool should match the existing grade at this location.

19. Next, position the first grade control structure, which is located immediately upstream of the outlet pool. The elevation of the bottom invert of the grade control structure should be set to the elevation of the top of the outlet pool. The grade control structure should rise 1 foot over its length, making its top invert elevation 1 foot higher than its bottom invert elevation.

20. Place a footer boulder beneath the downstream end of the grade control structure. The upstream face of the footer boulder should be placed to match the downstream face of the grade control structure. The top of the footer boulder should be placed at an elevation that is 6" below the top of the outlet pool (see **Figure RSC-6**).

21. Place additional boulders to form the downstream end of the grade control structure. The position of downstream face of the boulders should be placed to match the position of the upstream face of the footer boulder (**Figure RSC-6**). The boulders should extend, in a parabolic shape, across the width of the RSC System.

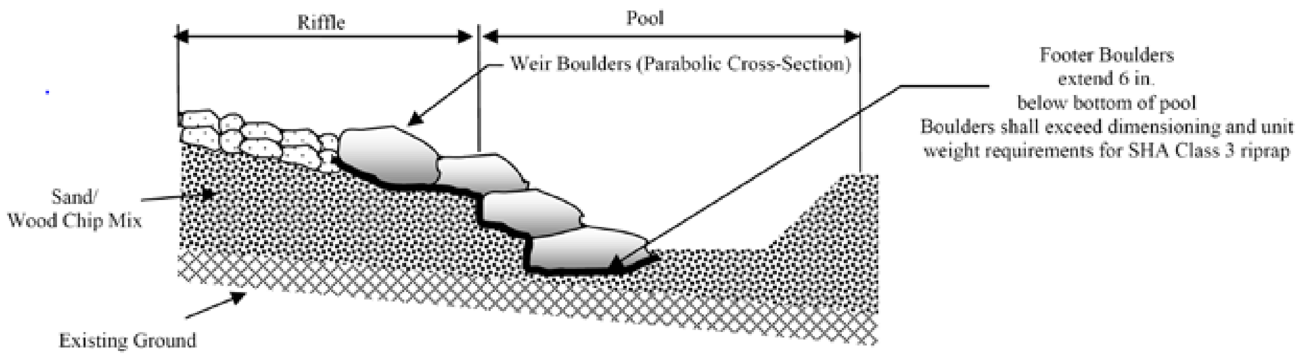

Figure RSC-6. Typical Position of Weir Boulders in Relation to Riffles and Pools (Source: Anne Arundel County, 2011).

22. Place cobble to form the remainder of the grade control structure. The cobble should extend across the width and remaining length of the grade control structure. The cobble should be placed to the depth of the grade control structures (in cross-section view) determined in Step 7b, with a top invert elevation that is that 1 foot greater than the bottom invert elevation.

23. Below the grade control structure, position a cobble apron to provide a stable flow path from the bottom invert of the grade control structure to the bottom of the downstream pool when the pools are dry. The cobble apron should be approximately 5 feet wide and 3 feet long.

24. Position the second pool above the first grade control structure. The elevation of the top of the pool should be set equal to the elevation of the top invert of the first grade control structure.

25. Repeat Steps 19-24, positioning grade control structures and pools until the starting point of the RSC System is reached. The elevation of the entry pool (and the elevation of the top invert of the upstream-most grade control structure) should be set at an elevation that will slightly backwater the inlet pipe, culvert or swale. As noted in Step 5, one or more cascades may be necessary to traverse steeper parts of the RSC flow path.

26. Position large woody debris in each of the pools. Top dress the sides (outside the main flow path) of the RSC System with compost and a temporary cover seed mix. Include stabilization, seeding and top dressing notes on the design plans.

27. Draft a planting plan, making sure that native plants are placed in appropriate planting zones and water depths.

RSC-4.2. Design Checklist for Regenerative Stormwater Conveyance Systems

Table RSC-5 is a design checklist adapted from Anne Arundel County (2011). This checklist provides additional details on each design step.

Table RSC-5. Regenerative Stormwater Conveyance System Design Checklist[1]

RSC Item	Check
Hydrology	Delineate drainage area, landcovers, and soil to the most downstream point of the RSC System.
	Develop TR55/TR20 model run to calculate the predevelopment and post-development peak discharges.
	Utilize TR-55 to calculate the required water quality volume and water quantity volume of storage to be controlled within the system.
	Conduct a downstream investigation to check the adequacy of the outfall system.
Hydraulics	Check the conveyance design (width, depth, slope) to ensure safe conveyance of the 100-year storm over the riffle/weir/cascade channels and that stable design dimensions for the cobbles and sandstone boulders are provided.
	Check the calculated minimum pool depth to ensure that sufficient pool depth is provided to dissipate the upstream energies properly.
	Check the post-development stream power for the 100-year storm to ensure that it is rendered equal to the predevelopment stream power. (Note: this requires that sufficient RSC length and number of pools be provided)
	Check that the storage volume within the pools and voids meet the required quantity management storage volume prescribed for the project and calculated using TR-55.
Alignment	Does the alignment follow the natural drainage path and are efforts made to avoid impacts to natural resources such as trees and wetlands?
Tree Protection	Have specimen trees been identified and a tree protection plan been developed?

RSC Item	Check
Downstream tie-in	Does the RSC System extend downstream to a point where the outfall is considered stable?
	Has adequate downstream tie-in/transition been provided to address downstream instability and to ensure the outfall remains stable?
Longitudinal Slope	Have the riffle segments been placed with a slope flatter than 5%?
	Have the pool segments been placed with a slope flatter than 1%?
	Have cascades been placed at no more than 1H:1V slope with double-lined boulders, and the height of any single cascade does not exceed 5 ft?
Pool Design	Are the side slopes for the pool (from all unarmored segments) 3H:1V or flatter?
	Does the depth of the pool exceed the minimum calculated depth based on the upstream velocities? The design of the riffle and weir shall be modified such as not to result in pool depth exceeding 3 ft.
	Does the length of the pool exceed the minimum required 10 ft and allow sufficient length to accommodate the 3H:1V slope on unarmored sides?
Riffle Channel Design	Is the channel parabolic in shape?
	Do the width, depth, and slope meet the design requirement and allow safe conveyance of the 100-year storm?
	Are the d0 cobble sizes adequate for accommodating the 100-year velocities? Note: d0 cobble size shall be specified on the plan, profile, and cross-section. The d0 is the minimum diameter size for the cobble stone. Smaller material shall be rejected by the inspector.
	Is the Width/Depth Ratio for the Riffle/Weir section at least 10W:1D?
Weir Design	Are the boulders forming the weir 3-4 times larger than the calculated d0?
	Are the footer boulders extended/anchored at least 6 inches below the lowest point of the scour pool?
	Does the cross-section for the weir safely convey the 100-year storm?
	Is filter fabric placed under the sandstone boulders?

RSC Item	Check
Cascade Design	Are the cascades armored with sandstone weir over filter fabric and the height does not exceed 5 ft at any given location?
	Are three pools provided following the cascade, with adequate weirs separating each pool structure and designed in a manner to safely convey the 100-year storm?
Cross section Drawings	Has the designer provided typical detail sections for the riffle, stone weirs and pools where needed and actual cross sections along the alignment at frequent intervals to reflect changes in the grading? Note: the cross-sections shall be developed based on the geometric alignment and shall show the station numbers, existing grade, proposed grade, and sand mix/stone structure detail.
	Has the designer shown the 100-year storm water surface elevation on the typical and actual cross-sections?
Profile Drawings	Has the designer provided a longitudinal profile along the centerline of the alignment and shown invert and top elevations of all structures and the 100-year water surface elevation?
Plan Sheets	Has proposed grading been provided, and is minimum/maximum dimensioning requirements met?
	Has the 100-year water surface elevation been plotted on the plan?
	Is the 100-year water surface elevation sufficiently contained within easements and is below all habitable structures?
E&S	Has adequate erosion and sediment control plan been implemented upstream of the RSC System?
Maintenance	Has a permanent and direct maintenance access been provided to all sandstone weirs and pools?
	Has a maintenance agreement been signed and recorded for private RSC structures?
Monitoring Plan	Has a monitoring/maintenance plan been developed as prescribed in the design guidelines and is it clearly shown on the plan?
Planting	Has mulching and hydro-seeding been prescribed for the entire system?
	Has the designer paid special attention to the use of native material, diversity, and dense placement of plant material within appropriate wetness zones throughout the site?

[1]*Adapted from Anne Arundel County (2011).*

RSC-4.3. Signage

An RSC unit in highly visible open space areas should be marked to designate it as a stormwater management facility. The signage should indicate (1) its water quality purpose, (2) that it may pond briefly after a storm, and (3) that it is not to be disturbed except for required maintenance.

RSC-4.4. Regenerative Stormwater Conveyance System Landscaping

A comprehensive plant list for landscaping of stormwater practices can be found in Appendix F, BMP Landscaping & Plant Lists. The plant list in this appendix includes a column specifically for RSC. Vegetation plays a critical role in the ability of an RSC System to mimic natural processes (Anne Arundel County, 2011). Native plants should be specified to create a diverse and dense planting plan according to various wetness zones within the RSC System.

4.2.7. Regenerative Stormwater Conveyance System (RSC)

RSC-5. Materials Specifications

To the maximum extent possible, the materials used to construct RSC Systems should be obtained from local suppliers.

In general, materials that have a natural appearance (e.g. rounded edges, brown or dark grey in color) should be used to construct the grade control structures. However, some compromises may need to be made to prevent the materials from making RSC Systems too expensive to construct. The materials listed in **Table RSC-6** should be used to construct the grade control structures, in order of preference.

Table RSC-6. Regenerative Stormwater Conveyance System Material Specifications

Material	Specification
Footer Boulders	1. Boulders salvaged from construction sites that have a natural appearance and are equivalent in size to Class 3 Rip Rap (average diameter of 26.4 inches). 2. Boulders available from local stone producers and suppliers that have a natural appearance and are equivalent in size to Class 3 Rip Rap. 3. Class 3 Rip Rap. 4. Class 2 Rip Rap (average diameter of 19.2 inches) may be used when Class 3 Rip Rap is not available and maximum allowable velocities are not exceeded in the RSC System.
Cobble	1. Cobble available from local stone producers and suppliers that has a natural appearance and is equivalent in size to Gabion Stone (minimum diameter of 6 inches). 2. Gabion Stone. 3. If larger material is needed, Class A1 Rip Rap (average diameter of 9.6 inches) or Class 1 Rip Rap (average diameter of 13.2 inches) can be used in place of or combination with Gabion Stone.

Material	Specification
Sand/ Woodchip Bed	The sand component of the sand/wood chip bed shall meet the AASHTO-M-6 or ASTM-C-33, 0.02 inches to 0.04 inches in size. Sand shall be a silica-based coarse aggregate. Substitutions such as Diabase and Graystone (AASHTO) #10 are not acceptable. No calcium carbonate or dolomitic sand substitutions are acceptable. No "rock dust" can be used for sand. Locally-approved pulverized glass may be substituted if the local authority undertakes testing to verify compliance with the particle size specification. No art glass shall be used for a pulverized glass material. For woodchips, use aged, shredded hardwood chips/mulch. The woodchips shall be added to the sand mix, approximately 20 percent by volume, to increase the organic content and promote plant growth and sustainability.
Choker Stone	The choker stone layer between the sand bed and the bank run gravel should be clean, washed #8 or #78 stone.
Bank Run Gravel	The bank run gravel layer that is placed beneath the sand bed/choker stone layers should be constructed using clean, washed # 5 or # 57 coarse aggregate. The bank run gravel layer that is placed on top of the sand bed should be constructed using stone available from local stone producers and suppliers that is equivalent in size to # 5 or # 57 coarse aggregate. If this material is not available, # 5 or # 57 coarse aggregate can be used.
Compost	The compost used as a top dressing over the RSC System should consist of a 100% organic compost, with a pH of between 6.0 and 7.0, a moisture content of between 30 and 55%, and a particle size of 0.25 inches or less.
Wood Chips	The wood chips used within the sand bed should consist of double-shredded or double-ground hardwood mulch that is free of dyes, chromated copper arsenate and other preservatives.
Plant Materials	See **Section RSC-4.4 and Appendix F**

RSC-6. Design Adaptations

RSC-6.1. Karst Terrain

RSC Systems have largely been used in coastal plain settings, but could be adapted to karst with certain design considerations. While RSC produces shallower ponding than conventional stormwater practices (e.g., Ponds and Wetlands), designs that infiltrate a lot of water through the sand/woodchip bed into underlying groundwater are not recommended in any area with a moderate or high risk of sinkhole formation (Hyland, 2005). On the other hand, RSC designs that meet a 3 foot separation distance to karst bedrock features and/or contain an impermeable bottom liner may work well. However, since RSC is placed within existing drainage systems, it may be difficult to avoid proximity to bedrock in some places. In general, smaller-scale RSC Systems are advisable in karst areas, and geotechnical studies should be conducted to ascertain structural suitability.

RSC-6.2. Steep Slopes

RSC can be used on moderate to steep slopes. However, longitudinal slopes of 10% or less are recommended.

RSC-6.3. Cold Climate and Winter Performance

Many different kinds of salting and sanding materials are applied in West Virginia during winter conditions. These can clog the sand/woodchip bed of RSC Systems if the proper design approach is not used, particularly for practices that treat road and highway runoff. In these cases, pre-treatment cells or separate upgradient sediment storage areas should be employed to try to keep as many of these materials as possible off of the main RSC conveyance system.

RSC-6.4. Stormwater Retrofitting

RSC is a good candidate for retrofitting in cases where the existing drainage or conveyance system is eroded and/or incised. In these cases, RSC not only provides stable conveyance, but restores ecosystem and hydraulic functions associated with non-tidal streams and wetlands. In the retrofit context, RSC can also be combined with other upgradient runoff reduction practices to restore hydrologic function and water quality. As with other stormwater practices, many retrofit designs cannot meet the full sizing requirements outlined in **Section RSC-4**, so it is important to define retrofit objectives and the desired Design Volume necessary to meet TMDL or watershed restoration goals.

4.2.7. Regenerative Stormwater Conveyance System (RSC)

RSC-7. Construction & Installation

See Anne Arundel County (2011) for a construction inspection checklist to be applied to RSC.

4.2.7. Regenerative Stormwater Conveyance System (RSC)

RSC-8. Maintenance Criteria

Maintenance tasks and frequency will vary depending on the size and location of the RSC System, the landscaping template chosen, and the type of surface cover in the practice. A generalized summary of common maintenance tasks and their frequency is provided in **Table RSC-7**.

Table RSC-7. Recommended Maintenance Tasks for RSC Systems

Maintenance Tasks	Frequency
▪ For the first 6 months following construction, the practice and drainage area should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. ▪ Check for erosion or "end-cutting" of weirs and riffle structures. ▪ Check for stable water levels in pools. ▪ Conduct any needed repairs or stabilization. ▪ Inspectors should look for bare or eroding areas in the contributing drainage area or around the RSC channel, and make sure they are immediately stabilized with grass cover. ▪ One-time, spot fertilization may be needed for initial plantings. ▪ Watering is needed once a week during the first 2 months, and then as needed during first growing season (April-October), depending on rainfall. ▪ Remove and replace dead plants. Up to 10% of the plant stock may die off in the first year, so construction contracts should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.	Upon establishment
▪ Routine maintenance of vegetation: weeding, pruning, etc. ▪ Trash removal	Approximately 4 times a year
▪ Add reinforcement planting to maintain desired the vegetation density ▪ Remove any dead or diseased plants ▪ Stabilize the contributing drainage area to prevent erosion	As needed
▪ Conduct a maintenance inspection ▪ Check structural stability of weirs, riffles, pools; check for desired water level in pools ▪ Prune trees and shrubs ▪ Remove invasive plants using recommended control methods ▪ Remove sediment in pre-treatment cells and inflow points	Annually
▪ Remove sediment in pools if necessary ▪ Repair any structural damage to weirs, riffles, pools, or tie-in to downstream channel	Once every 2 to 3 years

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each RSC System. Example maintenance inspection checklists can be found in Appendix A of the Manual.

REFERENCES

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4.2.8. Rainwater Harvesting (RH)

RH-1. Introduction

Source: Rainwater Management Solutions, Inc.

Rainwater Harvesting systems intercept, divert, store and release rainfall for future use. Their runoff and pollutant reduction rates are based on the system's size, configuration, water demand, and use of secondary practices to manage overflow from Rainwater Harvesting systems.

Rainwater Harvesting can be used to:

- Manage the first one inch of rainfall on-site, in part or in whole, depending on the tank size, year-round demand for the water, and use of a secondary, downstream practice to manage tank drawdowns and overflows (See **Table RH-1**).
- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs) (See **Table RH-2**).
- Retrofit existing developed areas

The capture and reuse of rainwater can significantly reduce stormwater runoff volumes and pollutant loads. By providing a reliable and renewable source of water to end users, Rainwater Harvesting systems can also have environmental and economic benefits beyond stormwater management (e.g., increased water conservation, water supply during drought and mandatory municipal water supply restrictions, decreased demand on municipal or groundwater supply, decreased water costs for the end-user, potential for increased groundwater recharge).

Rainwater that falls on a rooftop is collected and conveyed into an above- or below-ground storage tank where it can be used for non-potable water uses and on-site stormwater infiltration or treatment. Non-potable uses may include flushing of toilets and urinals inside buildings, landscape irrigation, exterior washing (e.g. car washes, building facades, sidewalks, street sweepers, fire trucks, etc.), fire suppression (sprinkler) systems, supply for chilled water cooling towers, replenishing and operation of water features and water fountains, and laundry, if approved by the local authority.

Figure RH-1 further illustrates typical Rainwater Harvesting applications, and **Figure RH-2** illustrates a typical schematic. **Table RH-1** describes the runoff reduction performance and **Table RH-2** describes the pollutant removal performance of Rainwater Harvesting systems. **Table RH-3** is a design checklist to help guide the design process for Rainwater Harvesting systems.

A Cistern Design Spreadsheet is provided as a companion to this specification, and is discussed in more detail in **Supplements 4.2.8.A (Description of Spreadsheet), 4.2.8.B (Step-By-Step Instructions), and 4.2.8.C (Notes on Methodology**) at the end of this specification..

In this specification, the terms cistern and tank are used interchangeably to refer to the storage component of a Rainwater Harvesting system.

RH-1.1. Planning the Practice – Example Applications

Figure RH-1. Example Applications of Rainwater Harvesting

Underground Tank to Irrigate Turf Fields   Source: City of Charlottesville, VA

Vehicle Wash Water   Source: City of Charlottesville

Indoor Uses: Laundry, Toilet Flushing, Etc.

Figure RH-2. Schematic of Typical Rainwater Harvesting System

1. **Rooftop surface** – Sections RH-3 & RH-4.1
2. **Collection & conveyance system** – Section RH-4.6
3. **Pretreatment** – Section RH-4.7
4. **Storage tank configuration** – Sections RH-4.3 & RH-4.8
5. **Distribution system** – Section RH-4.1
6. **Overflow and/or treatment in secondary runoff reduction practice** – Sections RH-4.3 & RH-4.9

RH-1.2. Rainwater Harvesting Design Options & Performance

Table RH-1 describes the runoff reduction performance functions for Rainwater Harvesting systems. Rainwater Harvesting system design does not have a Level 1 and Level 2 design. Runoff reduction credits are based on the total amount of annual internal water reuse, outdoor water reuse, and tank dewatering discharge calculated to be achieved by the tank system using the Cistern Design Spreadsheet. As noted in **Table RH-2**, pollutant removal rates for the purposes of TMDLs and watershed plans are equal to the runoff reduction rates derived from the Cistern Design Spreadsheet.

Table RH-1. Rainwater Harvesting Runoff Reduction Performance

Description	Applications	Performance Achieved Toward Reducing 1" of Rainfall
Standard Design -- • Year-round use of stored water and/or downstream secondary runoff reduction practice to manage drawdown and overflow from the tank • System components as per the specification	Usually sites with substantial rooftop areas and defined beneficial uses for the stored water. Small-scale (e.g., residential, small-scale commercial) applications are also possible if there are defined outdoor and/or indoor uses of the water.	Credit is variable and determined using the Cistern Design Spreadsheet. Design Volume credit up to 100% is possible if all water from storms with rainfall of 1 inch or less is used through demand, and the tank is sized such that no overflow from this size storm event occurs.

Table RH-2. Pollutant Removal Performance Values for Rainwater Harvesting

Design Level	Total Suspended Solids (TSS)[1]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN) [1]
One Design Level	TSS = runoff reduction rate from Cistern Design Spreadsheet[1]	TP & TN = runoff reduction rate from Cistern Design Spreadsheet[1]

[1] *TSS and nutrient pollutant load reduction is equal to the runoff reduction rate. No additional pollutant removal rate is applied to the Rainwater Harvesting system. If secondary or downstream practices are used in conjunction with Rainwater Harvesting, TSS and nutrient removal rates are in accordance with the applicable rates for those practices, as noted in* **Chapter 3** *of this Manual and the individual specifications in* **Chapter 4**.

RH-1.3. Rainwater Harvesting Design Checklist

Table RH-3. Rainwater Harvesting Design Checklist

CHECKLIST

- ☐ Evaluate site to determine if rainwater can be harvested from rooftops, if there is year-round demand for the collected water, and if local regulatory authorities will allow the practice.
- ☐ Determine the Treatment Volume (Tv) for the target drainage area using the Design Compliance Spreadsheet. Determine if other downstream best management practices (BMPs) will be used in conjunction with Rainwater Harvesting to meet the site Tv goal.
- ☐ Complete the Cistern Design Spreadsheet (see Section RH-4.5 and Supplement 4.2.8.B and C) to evaluate various tank sizes and configurations (see Sections RH-4.2 and RH-4.3) to meet projected demand. The Cistern Design Spreadsheet will generate a runoff reduction rate to "plug into" the Design Compliance Spreadsheet (see below). This rate will be based on tank size, water demand, and possible use of a downstream runoff reduction practice.
- ☐ Using the runoff reduction % generated in the Cistern Design Spreadsheet, return to the Design Compliance Spreadsheet and check overall compliance with the 1-inch reduction standard. Downstream practices may be needed if: (1) there is not a year-round use for the collected water, and/or (2) additional practices are needed on the site to capture the Tv.
- ☐ Check Rainwater Harvesting sizing guidance and ensure adequate storage volume in the cistern and conveyance system – Section RH-4
- ☐ Check design adaptations appropriate to the site – Section RH-6
- ☐ Design Rainwater Harvesting system in accordance with design criteria and typical details – Sections RH-2 & RH-4
- ☐ If downstream runoff reduction practices will be installed to treat outflow and overflow from the cistern and/or to provide additional runoff reduction credit, go to the applicable specification in this Manual for design guidance on that practice.
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence notes.

4.2.8. Rainwater Harvesting (RH)

RH- 2. Typical Details

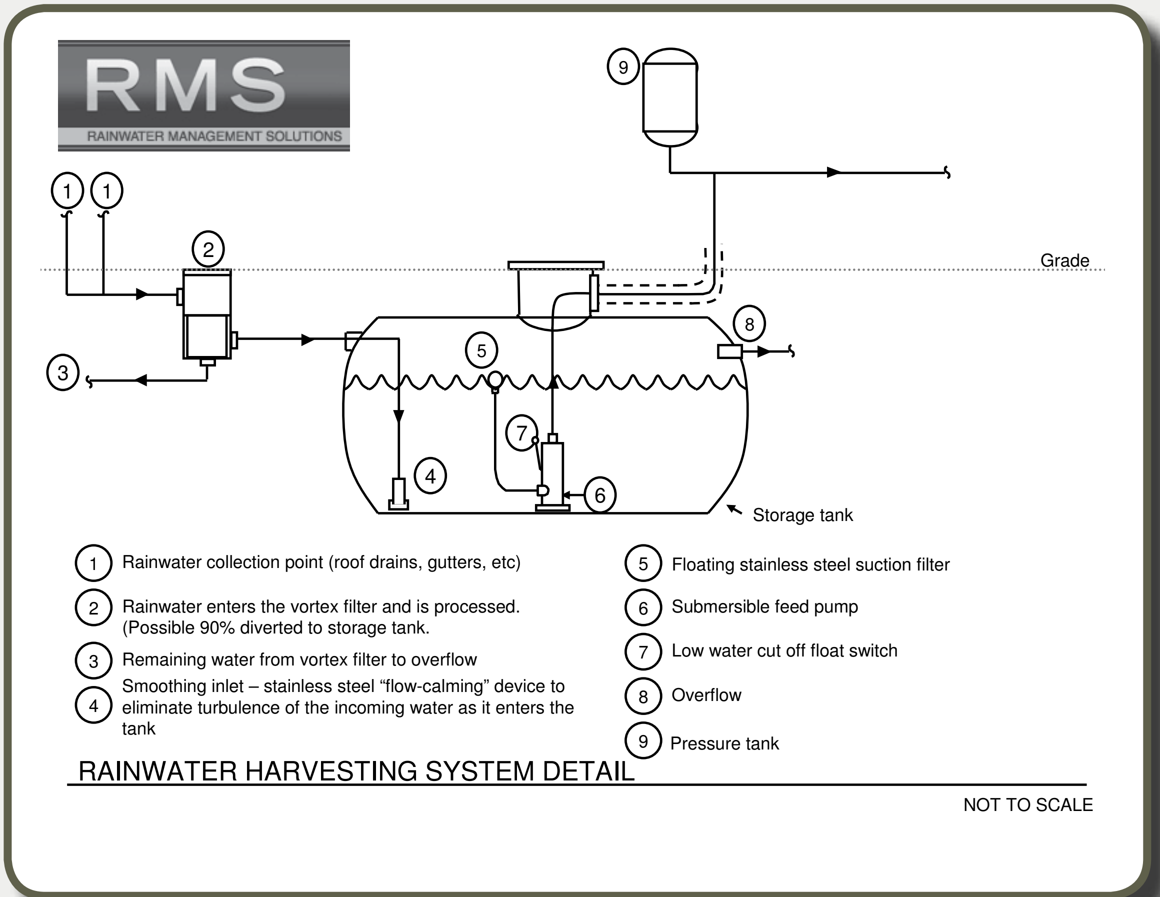

Figure RH-3. Typical Components of Rainwater Harvesting Systems (Source: Rainwater Management Solutions)

Additional details and schematics are provided in **Section RH-4**. **Figures RH-4 through RH-6** provide typical schematics of cistern and piping system configurations, based on the design objectives (year-round internal use, external seasonal irrigation, etc.). **Figures RH-7 through RH-9** provide typical schematics of cistern tank configurations, based on the desired Design Volume (Dv) and stormwater management objectives (Dv only, detention storage, etc.).

RH-3. Feasibility Criteria and Design Considerations

A number of site-specific features influence how Rainwater Harvesting systems are designed and/or utilized. These should not be considered comprehensive and conclusive considerations, but rather some recommendations that should be considered during the process of planning to incorporate Rainwater Harvesting systems into the site design. The following are key considerations for Rainwater Harvesting feasibility.

Plumbing Codes. This specification does not address indoor plumbing or disinfection issues. Designers and plan reviewers should consult the local and state building and health codes to determine the allowable indoor uses and required treatment for harvested rainwater. In cases where a municipal backup supply is used, Rainwater Harvesting systems must have backflow preventers or air gaps to keep harvested water separate from the main water supply. Pipes and spigots using rainwater must be clearly labeled as non-potable.

Available Space. Adequate space is needed to house the storage tank and any overflow. Space limitations are rarely a concern with Rainwater Harvesting systems if they are considered during the initial building design and site layout of a residential or commercial development. Storage tanks can be placed underground, indoors, on rooftops that are structurally designed to support the added weight, and adjacent to buildings. Designers can work with architects and landscape architects to creatively site the tanks. Underground utilities or other obstructions should always be identified prior to final determination of the tank location.

Site Topography. Site topography and storage tank location should be considered as they relate to all of the inlet and outlet invert elevations in the Rainwater Harvesting system.

The final invert of the outlet pipe from the storage tank must match the invert of the receiving mechanism (natural channel, storm drain system, etc.) that receives this overflow. The elevation drops associated with the various components of a Rainwater Harvesting system and the resulting invert elevations should be considered early in the design, in order to ensure that the Rainwater Harvesting system is feasible for the particular site.

Site topography and storage tank location will also affect pumping requirements. Locating storage tanks in low areas will make it easier to route roof drains from buildings to cisterns. However, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigated areas situated on higher ground. Conversely, placing storage tanks at higher elevations may require larger diameter roof drains with smaller slopes. However, this will also reduce the amount of pumping needed for distribution. It is often best to locate a cistern close to the building, ensuring that minimal roof drain slopes and limited enclosure of roof drain pipes are needed.

Consider Elevations Early in Design Process

The elevation drops associated with the various components of a Rainwater Harvesting system and the resulting invert elevations should be considered early in the design, in order to ensure that the Rainwater Harvesting system is feasible for the particular site.

Available Hydraulic Head. The required hydraulic head depends on the intended use of the water. For residential landscaping uses, the cistern should be sited up-gradient of the landscaping areas or on a raised stand. Pumps are commonly used to convey stored rainwater to the end use in order to provide the required head. When the water is being routed from the cistern to the inside of a building for non-potable use, often a pump is used to feed a much smaller pressure tank inside the building which then serves the internal water demands. Cisterns can also use gravity to accomplish indoor residential uses (e.g., laundry) that do not require high water pressure.

Water Table. Underground storage tanks are most appropriate in areas where the tank can be buried above the water table. The tank should be located in a manner that will not subject it to flooding. In areas where the tank is to be buried partially below the water table, special design features must be employed, such as sufficiently securing the tank (to keep it from "floating"), and conducting buoyancy calculations when the tank is empty. The tank may need to be secured appropriately with fasteners or weighted to avoid uplift buoyancy. The tank must also be installed according to the tank manufacturer's specifications.

Soils. Storage tanks should only be placed on native soils or on fill in accordance with the manufacturer's guidelines. The bearing capacity of the soil upon which the cistern will be placed must be considered, as full cisterns can be very heavy. This is particularly important for above-ground cisterns, as significant settling could cause the cistern to lean or in some cases to potentially topple. A sufficient aggregate, or concrete base, may be appropriate depending on the soils. The pH of the soil should also be considered in relation to its interaction with the cistern material.

Proximity of Underground Utilities. All underground utilities must be taken into consideration during the design of underground Rainwater Harvesting systems, treating all of the Rainwater Harvesting system components and storm drains as typical stormwater facilities and pipes. The underground utilities must be marked and avoided during the installation of underground tanks and piping associated with the system.

Contributing Drainage Area. The contributing drainage area (CDA) to the cistern is the impervious area draining to the tank. Only rooftop surfaces should be included in the CDA. Parking lots and other paved areas can only be used with appropriate treatment (oil/water separators) and approval by the local review authority. Areas of any size, including portions of roofs, can be used based on the sizing guidelines in this design specification. Runoff should be routed directly from rooftops to Rainwater Harvesting systems in closed roof drain systems or storm drain pipes, avoiding surface drainage, which could allow for increased contamination of the water.

Rooftop Material. The quality of the harvested rainwater will vary according to the roof material over which it flows. Water harvested from certain types of rooftops, such as asphalt sealcoats, tar and gravel, painted roofs, galvanized metal roofs, sheet metal or any material that may contain asbestos may leach trace metals and other toxic compounds. In general, harvesting rainwater from such roofs should be avoided. If a sealant or painted roof surface is desired, it is recommended to use one that has been certified for such purposes by the National Sanitation Foundation (ANSI/NSF standard).

Water Quality of Rainwater. Designers should also note that the pH of rainfall in West Virginia tends to be acidic (ranging from 4.0 to 5.5), which may result in leaching of metals from the roof surface, tank lining or water laterals to interior connections. Once rainfall leaves rooftop surfaces, pH levels tend to be slightly higher, ranging from 5.5 to 6.0. Limestone or other materials may be added in the tank to buffer acidity, if desired.

Hotspot Land Uses. Harvesting rainwater can be an effective method to prevent contamination of rooftop runoff that would result from mixing it with ground-level runoff from a stormwater hotspot operation. In some cases, however, industrial roof surfaces may also be designated as stormwater hotspots.

Setbacks from Buildings. Cistern overflow devices should be designed to avoid causing ponding or soil saturation within 10 feet of building foundations. Tanks must be designed to be watertight to prevent water damage when placed near building foundations. In general, it is recommended that underground tanks be set at least 10 feet from any building foundation.

Vehicle Loading. Whenever possible, underground Rainwater Harvesting systems should be placed in areas without vehicle traffic or be designed to support live loads from heavy trucks, a requirement that may significantly increase construction costs.

RH-4. Design Criteria

RH-4.1. System Components

System Components: There are six primary components of a Rainwater Harvesting system (see **Figure RH-2**):

- Rooftop surface
- Collection and conveyance system (e.g., gutter and downspouts)
- Pretreatment
- Storage tank
- Distribution system
- Overflow, filter path or secondary stormwater retention practice

The system components are discussed below:

Rooftop Surface: The rooftop should be made of smooth, non-porous material with efficient drainage either from a sloped roof or an efficient roof drain system. Slow drainage of the roof leads to poor rinsing and a prolonged first flush, which can decrease water quality. If the harvested rainwater will be used for potable uses, or uses with significant human exposure (e.g., pool filling, watering vegetable gardens), care should be taken in the choice of roof materials. Some materials may leach toxic chemicals, making the water unsafe for humans.

Collection and Conveyance System: The collection and conveyance system consists of the gutters, downspouts and pipes that channel rainfall into storage tanks. Gutters and downspouts should be designed as they would for a building without a Rainwater Harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for Rainwater Harvesting. Minimum slopes of gutters should be specified. See also **Section RH-4.6, Collection and Conveyance Design Criteria.**

Pretreatment: Pre-filtration is required to keep sediment, leaves, contaminants and other debris from the system. Leaf screens and gutter guards meet the minimal requirement for pre-filtration of small systems, although direct water filtration is preferred. All pre-filtration devices should be low-maintenance or maintenance-free. The purpose of pre-filtration is to significantly cut down on maintenance by preventing organic buildup in the tank, thereby decreasing microbial food sources. See also **Section RH-4.7, Pretreatment Design Criteria.**

Storage Tank: The storage tank is the most important and typically the most expensive component of a Rainwater Harvesting system. While many of the graphics and photos in this specification depict cisterns with a cylindrical shape, the tanks can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the tanks will be installed. For example, configurations can be rectangular, L-shaped, or stepped vertically to match the topography of a site.

Cistern capacities range from 250 to over 30,000 gallons. Multiple tanks can be placed adjacent to each other and connected with pipes to balance water levels and increase overall storage on-site as needed. Typical Rainwater Harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Storage tank volumes are calculated to meet the water demand and stormwater Design Volume objectives, as described in Section RH-4.8, Storage Tank Design Criteria of this specification.

Distribution System: Most distribution systems require a pump to convey harvested rainwater from the storage tank to its final destination, whether inside the building, an automated irrigation system, or gradually discharged to a secondary runoff reduction practice. The Rainwater Harvesting system should be equipped with an appropriately-sized pump that produces sufficient pressure for all end-uses. The municipality may require the separate plumbing to be labeled as non-potable.

The typical pump and pressure tank arrangement consists of a multi-stage centrifugal pump, which draws water out of the storage tank and sends it into the pressure tank, where it is stored for distribution. When water is drawn out of the pressure tank, the pump activates to supply additional water to the distribution system. The backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.

Distribution lines from the Rainwater Harvesting system should be buried beneath the frost line. Lines from the Rainwater Harvesting system to the building should have shut-off valves that are accessible when snow cover is present. A drain plug or cleanout sump, also draining to a pervious area, should be installed to allow the system to be completely emptied, if needed.

Above-ground outdoor pipes should be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter.

Overflow, Filter Path and Secondary Runoff Reduction Practice: An overflow mechanism should be included in the Rainwater Harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the tank. Overflow pipes should have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe should be screened to prevent access to the tank by rodents and birds. See also Section RH-4.6, Collection and Conveyance Design Criteria.

The filter path is a pervious or grass corridor that extends from the overflow to the next runoff reduction practice, the street, an adequate existing or proposed channel, or the storm drain system. The filter path must be graded with a slope that results in sheet flow conditions. If compacted or impermeable soils are present along the filter path, Soil Amendments may be needed (see Appendix D). It is also recommended that the filter path be used for first flush diversions.

In many cases, Rainwater Harvesting system overflows are directed to a secondary runoff reduction practice to boost overall runoff reduction rates. These options are addressed in Section RH-4.9, On-Site Treatment in a Secondary Practice.

RH-4.2. Design Objectives and System Configurations

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a best management practice (BMP) plan:

Target Treatment Volume (Tv) = Volume associated with managing 1" of rainfall based on the size and land cover of the contributing drainage area (CDA), as determined by the Design Compliance Spreadsheet. Any given BMP may treat the full Tv or only part of it if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on storage in the practice, as prescribed in the BMP specification. For Rainwater Harvesting, Dv will equal Tv if the CDA is only the rooftop area directed to the Rainwater Harvesting practice. However, if Rainwater Harvesting is used in conjunction with downstream runoff reduction practices, the Dv of the Rainwater Harvesting practice can be a subset of the overall Tv. In such cases, the sum of the Dvs in the Rainwater Harvesting practice plus those of the other practices in the treatment train should equal the total drainage area Tv.

See **Chapter 3** for more information on the runoff reduction design methodology.

For the purposes of this sizing section, the sizing relates to the Dv of the Rainwater Harvesting practice being designed.

Many Rainwater Harvesting system variations can be designed to meet user demand and stormwater objectives. This specification focuses on providing a framework for addressing the Design Volume (Dv) objectives and achieving compliance with the regulations. From a Rainwater Harvesting standpoint, there are numerous potential configurations that could be implemented. However, this specification adheres to the following concepts in order to properly meet the stormwater on-site retention goals:

- System design is encouraged to use rainwater as a resource to meet on-site demand or in conjunction with other runoff reduction practices (especially those that promote groundwater recharge).
- Peak flow reduction (if needed to meet local detention requirements) is realized through reduced volume and temporary storage of runoff.

Credit Only Applies to Systems with Year-Round Water Use

Credit is only available for year-round drawdown/demand for the water. While seasonal practices (such as irrigation) may be incorporated into the site design, they are not, in and of themselves, considered adequate to derive a year-round runoff reduction credit. If only seasonal use of the water in envisioned, a secondary downstream runoff reduction practice can be incorporated in order to qualify for a runoff reduction credit. In this way, during the non-seasonal months, water can be drained from the tank slowly to be treated by the downstream practice.

The Rainwater Harvesting system design configurations presented in this specification are targeted for continuous (year-round) use of rainwater through (1) internal use, and (2) irrigation and/or treatment in a secondary runoff reduction practice. Three basic system configurations are described below.

Configuration 1: Year-round indoor use with optional seasonal outdoor use (Figure RH-4). The first configuration is for year round indoor use along with optional seasonal outdoor use, such as irrigation. Because there is no on-site secondary runoff reduction practice incorporated into the design for non-seasonal (or non-irrigation) months, the system must be designed and treatment credit awarded for the interior use only. (However, it should be noted that the seasonal irrigation will provide an economic benefit in terms of water usage). Stormwater credit can be enhanced by adding a secondary runoff reduction practice (see Configuration 3 below).

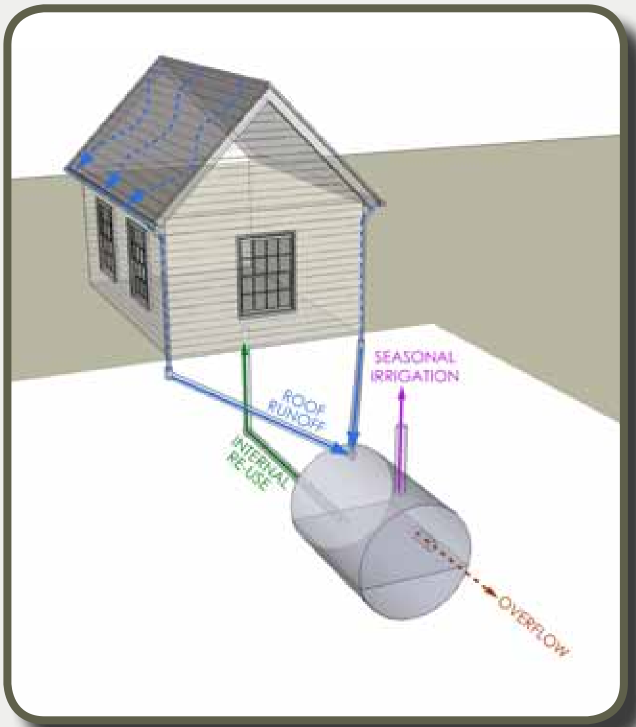

Figure RH-4. Configuration 1:Year-round indoor use with optional seasonal outdoor use. (Source:Alex Forasté)

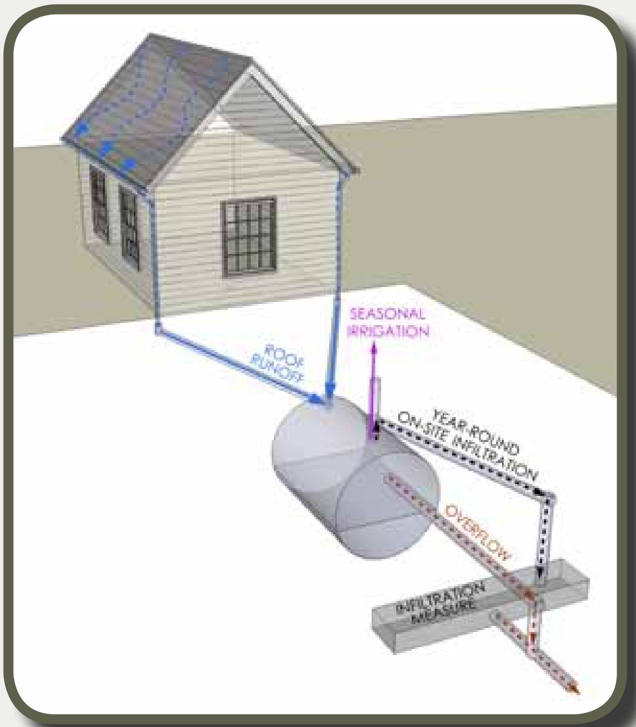

Figure RH-5. Configuration 2: Seasonal outdoor use and approved year-round secondary practice. (Source:Alex Forasté)

Configuration 2: Seasonal outdoor use and approved year-round secondary runoff reduction practice (Figure RH-5). The second configuration uses stored rainwater to meet a seasonal or intermittent water use, such as irrigation. However, because these uses are only intermittent or seasonal, this configuration also relies on an approved secondary practice for stormwater credit. Compared to a stand-alone BMP (without the up-gradient tank), the size and/or storage volume of the secondary practice can be reduced based on the storage in the tank (unless the secondary practice also receives runoff from other areas on the site).The tank's drawdown and release rate should be designed based on the infiltration properties, surface area, and capacity of the receiving secondary runoff reduction practice. The release rate therefore is typically much less than the flow rate that would result from routing a detention facility. The secondary practice should serve as a "backup" facility, especially during non-irrigation months. In this regard, the tank should provide some meaningful level of storage and reuse, accompanied by a small flow to the secondary practice. See Tank Design Set-Ups:Tank Design 3 for more information.

Configuration 3: Year-round indoor use, seasonal outdoor irrigation, and non-seasonal treatment in a secondary stormwater practice (Figure RH-6).The third configuration provides for a year-round internal non-potable water demand, and a seasonal outdoor, automated irrigation system demand. In addition, this configuration incorporates a secondary practice during non-irrigation (or non-seasonal) months in order to yield a greater stormwater credit. In this case, the drawdown due to seasonal irrigation must be compared to the drawdown due to water released to the secondary practice. The minimum of these two values is used for system modeling and stormwater credit purposes.

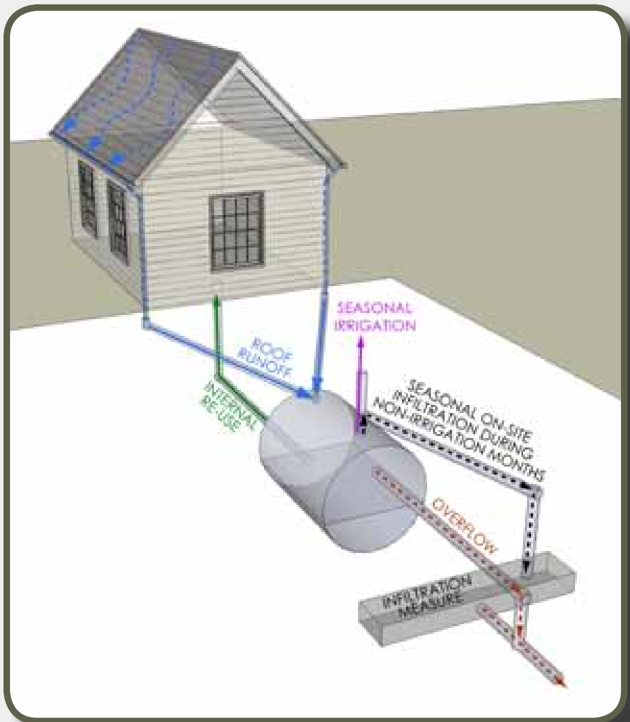

Figure RH-6. Configuration 3: Year-round indoor use, seasonal outdoor irrigation, and non-seasonal on-site treatment in secondary practice. (Source: Alex Forasté)

RH-4.3. Tank Design Set-Ups

Pre-fabricated Rainwater Harvesting cisterns typically range in size from 250 to over 30,000 gallons. There are three basic tank design configurations used to meet the various Rainwater Harvesting system configurations that are described below.

Tank Design 1. The first tank set-up (**Figure RH-7**) maximizes the available storage volume associated with the Dv to meet the desired level of stormwater credit. This layout also maximizes the storage that can be used to meet a demand. An emergency overflow exists near the top of the tank as the only gravity release outlet device (not including the pump, manway or inlets). It should be noted that it is possible to address channel and flood protection volumes (if required by local detention ordinances) with this tank configuration, but the primary purpose is to address the smaller Dv design storms.

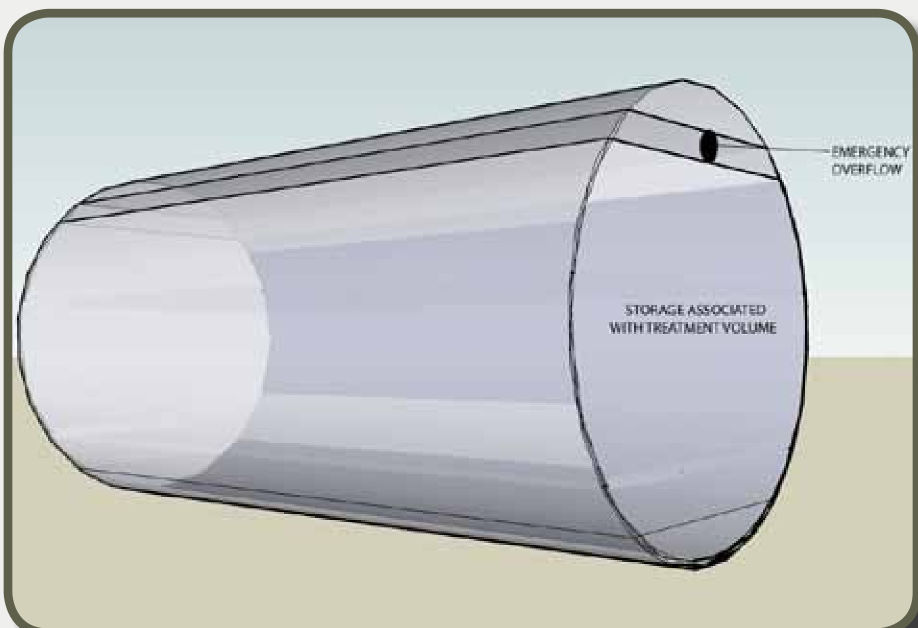

Figure RH-7. Tank Design 1: Storage Associated with Design Volume (Dv) only (Source: Alex Forasté)

Tank Design 2. The second tank set-up (**Figure RH-8**) uses tank storage to meet the Dv storage objectives as well as using an additional detention volume to also meet some or all of any required channel protection and/or flood protection detention volume requirements. An orifice outlet is provided at the top of the design storage for the Dv level, and an emergency overflow is located at the top of the detention volume level.

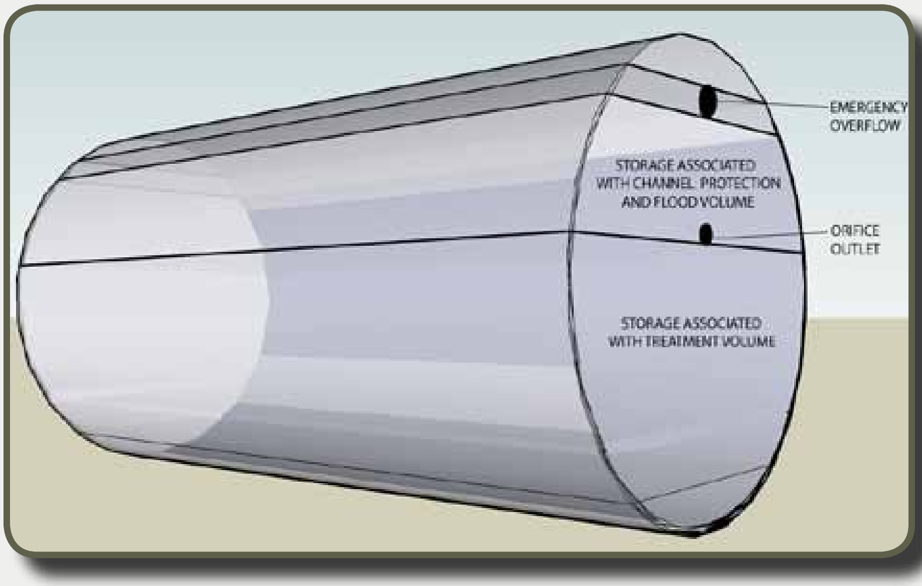

Figure RH-8. Tank Design 2: Storage Associated with Treatment, Channel Protection and Flood Volume (Source: Alex Forasté)

Tank Design 3. The third tank set-up (**Figure RH-9**) creates a constant drawdown within the system. The small orifice at the bottom of the tank needs to be routed to an appropriately designed secondary practice (e.g., Rain Garden, micro-scale Infiltration, Urban Bioretention) that will allow the rainwater to be treated and allow for groundwater recharge over time. The release should not be discharged to a receiving channel or storm drain without treatment, and maximum specified drawdown rates from this constant drawdown should be adhered to, since the primary function of the system is not intended to be detention.

While a small orifice is shown at the bottom of the tank in **Figure RH-9**, the orifice could be replaced with a pump that would serve the same purpose, conveying a limited amount of water to a secondary practice on a routine basis.

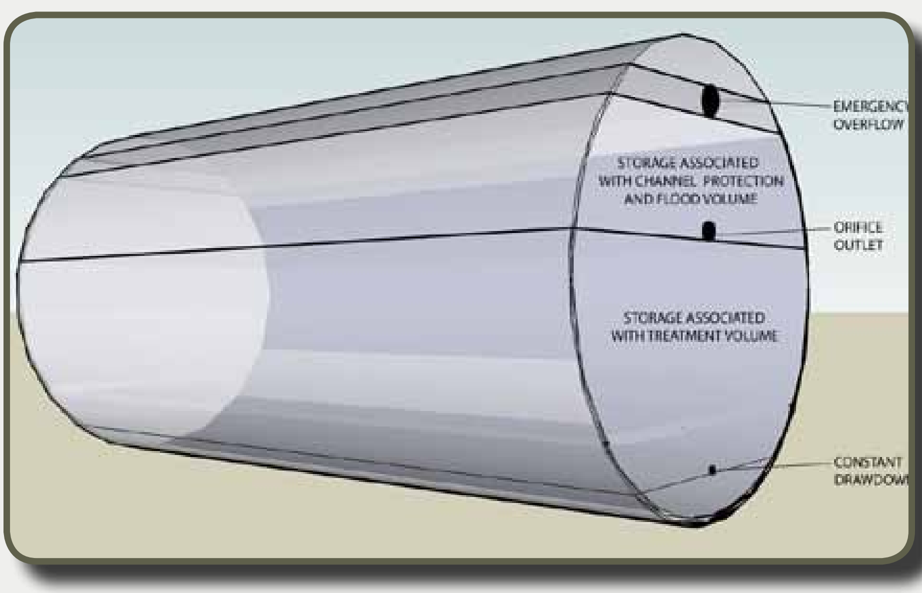

Figure RH-9. Tank Design 3: Constant drawdown, Storage Associated with Treatment, Channel Protection and Flood Volume (Source: Alex Forasté)

RH-4.4. Sizing of Rainwater Harvesting Systems

The Rainwater Harvesting cistern sizing criteria presented in this section was developed using best estimates of indoor and outdoor water demand, long-term rainfall data, and rooftop capture area data, using a spreadsheet model (Forasté and Lawson, 2009). The Cistern Design Spreadsheet is primarily intended to provide guidance in sizing cisterns and to quantify the runoff reduction volume credit for input into the Design Compliance Spreadsheet for stormwater management compliance purposes. A secondary objective of the spreadsheet is to increase the beneficial uses of the stored stormwater, treating it as a valuable natural resource.

Rainwater tank sizing is determined by accounting for varying precipitation levels, captured rooftop runoff, first flush diversion (through filters) and filter efficiency, low water cut-off volume, dynamic water levels at the beginning of various storms, storage needed for Design Volume (permanent storage), storage needed for temporary detention storage (if required by the local program), seasonal and year-round demand use and objectives, overflow volume, and freeboard volumes above high water levels during very large storms. See **Figure RH-10** for a graphical representation of these various incremental design volumes.

For the purposes of this sizing method, the Dv is assumed to be associated only with the rooftop area draining to the Rainwater Harvesting practice.

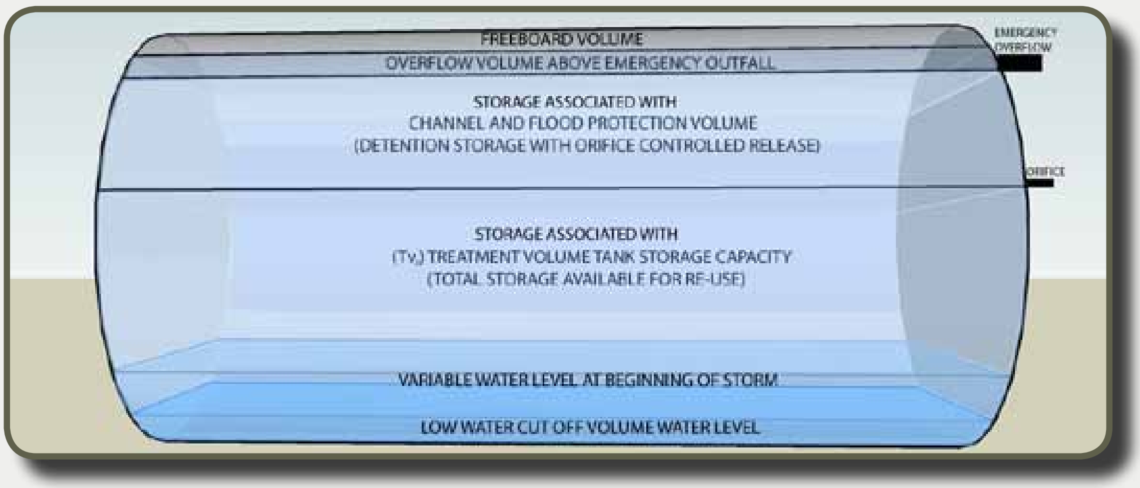

Figure RH-10. Incremental volumes associated with tank sizing. (Source: Alex Forasté)

RH-4.5. Cistern Design Spreadsheet

This specification is linked with the Cistern Design Spreadsheet. The spreadsheet uses daily rainfall data from four localities in West Virginia (Beckley, Morgantown, Moorefield, Huntington) to model performance parameters of the cistern under varying rooftop capture areas, demands on the system and tank size.

The Cistern Design Spreadsheet is a design tool for Rainwater Harvesting, but it is also used to derive the runoff reduction credit for a particular design (Forasté and Hirschman, 2010). This credit is then plugged into the Design Compliance Spreadsheet to gage site compliance. Often, Rainwater Harvesting will have to be used in conjunction with other downstream practices in order to meet the 1" performance standard.

The supplements to this specification provide detailed guidance on using the Cistern Design Spreadsheet. The supplements are as follows:

- Supplement 4.2.8.A is a description of the spreadsheet parameters, inputs needed to use the spreadsheet, and spreadsheet outputs that can be used for system design and deriving the runoff reduction credit.
- Supplement 4.2.8.B provides step-by-step guidance for using the various tabs in the spreadsheet.
- Supplement 4.2.8.C contains some additional notes on the spreadsheet methodology and assumptions.
- Supplement 4.2.8.D includes recommendations for Rainwater Harvesting plan submittals and a checklist that can be used by designers and plan reviewers.

RH-4.6. Collection and Conveyance Design Criteria

The following additional design criteria apply to collection and conveyance components of the Rainwater Harvesting system:

At a minimum, gutters should be sized with slopes specified to convey at least 1-inch/hour If the system will also be used for detention of larger storms, the gutters should be designed to convey the 2-yr and 15-yr storms, using the appropriate 2-yr and 15-yr storm intensities. In all cases, gutters should be hung at a minimum of 0.5% for 2/3 of the length and at 1% for the remaining 1/3 of the length.

Pipes connecting downspouts to the cistern tank should be at a minimum slope of 1.5% and sized/designed to convey the intended design storm, as specified above. In some cases, a steeper slope and larger sizes may be recommended and/or necessary to convey the required runoff, depending on the design objective and design storm intensity. Gutters and downspouts should be kept clean and free of debris and rust.

RH-4.7. Pretreatment Design Criteria

The following additional design criteria apply to pretreatment components of the Rainwater Harvesting system:

For larger tank systems, the initial first flush must be diverted from the system before rainwater enters the storage tank. Designers should note that the term "first flush" in Rainwater Harvesting design does not have the same meaning as has been applied historically in the design of stormwater treatment practices. In this specification, the term "first flush diversion" is used to distinguish it from the traditional stormwater management term "first flush." The amount can range between the first 0.02 to 0.06 inches of rooftop runoff.

The diverted flows (first flush diversion and overflow from the filter) must be directed to an acceptable flow path that will not cause erosion during a 2-yr storm or to an appropriate BMP on the property

Various first flush diverters are described below. In addition to the initial first flush diversion, filters have an associated efficiency curve that estimates the percentage of rooftop runoff that will be conveyed through the filter to the storage tank. If filters are not sized properly, a large portion of the rooftop runoff may be diverted and not conveyed to the tank at all. A design intensity of 1 inch/hour should be used for the purposes of sizing pre-tank conveyance and filter components. This design intensity captures a significant portion of the total rainfall during a large majority of rainfall events (NOAA, 2004). If the system will be used for detention of larger storms, the 2-yr and 15-yr storm intensities should be used for the design of the conveyance and pre-treatment portion of the system. For the 1-inch Dv, a minimum of 95% filter efficiency is required. This efficiency includes the first flush diversion.

- **First Flush Diverters:** First flush diverters direct the initial pulse of rainfall away from the storage tank. While leaf screens effectively remove larger debris such as leaves, twigs and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen and bird and rodent feces (**Figure RH-11**). Simple first flush diverters require active management, by draining the first flush water volume to a pervious area following each rainstorm. First flush diverters may be the preferred pre-treatment method if the water is to be used for indoor purposes. A vortex filter (see below) may serve as an effective pre-tank filtration device and first flush diverter.
- **Leaf Screens:** Leaf screens are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the storage tanks. Built-up debris can also harbor bacterial growth within gutters or downspouts (TWDB, 2005).
- **Roof Washers:** Roof washers are placed just ahead of storage tanks and are used to filter small debris from harvested rainwater (**Figure RH-12**). Roof washers consist of a tank, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30-microns (TWDB, 2005). The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.

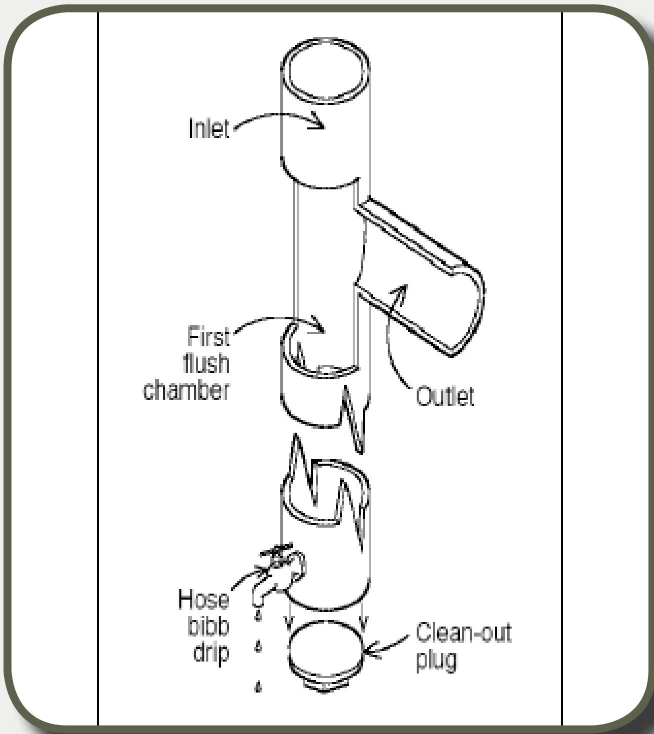

Figure RH-11. First Flush Diverter

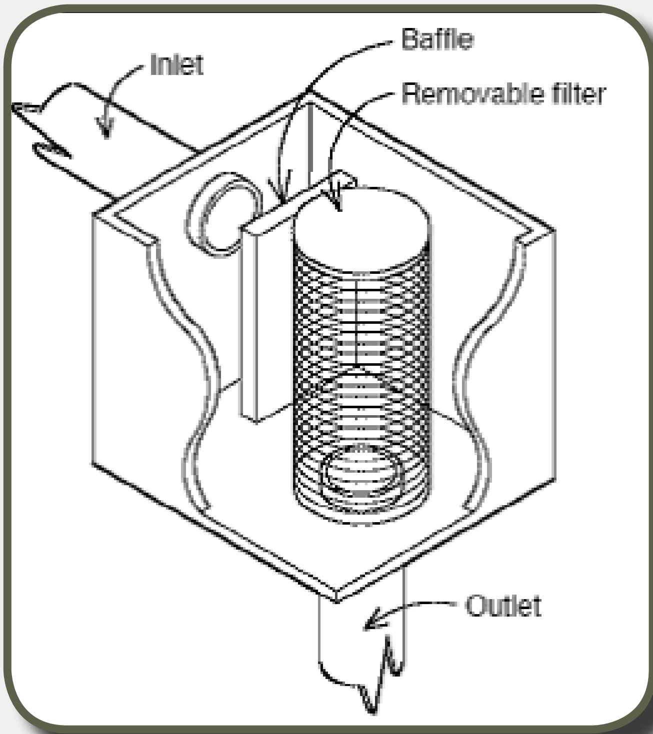

Figure RH-12. Roof Washer

Source: Texas Water Development Board (2005)

- **Vortex Filters:** For large scale applications, vortex filters can provide filtering of rooftop rainwater from larger rooftop areas. Figure RH-13 shows a plan view photograph showing the interior of a vortex filter with the top off. Figure RH-14 displays the filter just installed in the field prior to backfill.

Figure RH-13. Interior of Vortex Filter. (Source: Rainwater Management Solutions)

Figure RH-14. Installation of Vortex Filter prior to backfill. (Source: Rainwater Management Solutions)

RH-4.8. Storage Tank Design Criteria

The following factors that should be considered when designing a Rainwater Harvesting system and selecting a storage tank:

- Aboveground storage tanks should be UV and impact resistant.
- Underground storage tanks must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic, etc.).
- Storage tanks should have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. This access point should be secured to prevent unwanted access.
- The design of the tank should allow for removal of problematic sediment/debris that may accumulate in the tank, by vacuum or other methods.
- All Rainwater Harvesting systems should be sealed using a water-safe, non-toxic substance.
- Rainwater Harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. See **Section 5, Materials Specifications**.
- Storage tanks should be opaque or otherwise protected from direct sunlight to inhibit algae growth and should be screened to discourage mosquito breeding and reproduction.
- Dead storage below the outlet to the distribution system and an air gap at the top of the tank should be added to the total volume. For gravity-fed systems, a minimum of 6 inches of dead storage should be provided. For systems using a pump, the dead storage depth will be based on the pump specifications.
- Any hookup to a municipal backup water supply should have a backflow prevention device to keep municipal water separate from stored rainwater; this may include incorporating an air gap to separate the two supplies.

RH-4.9. On-Site Treatment in a Secondary Practice

Recent Rainwater Harvesting system design materials do not include guidance for on-site stormwater infiltration or "disposal". The basic approach is to provide a dedicated secondary runoff reduction practice on-site that will ensure water within the tank will gradually drawdown at a specified design rate between storm events. Secondary runoff reduction practices may include the following:

- Impervious Surface Disconnection (**Specification 4.2.2**); This may include release to a soil amended filter path
- Vegetated Filter Strip (**Specification 4.2.1**)
- Grass Swale (**Specification 4.2.**5)
- Infiltration and micro-Infiltration (**Specification 4.2.6**)
- Water Quality Swale, Rain Garden, or Urban Bioretention (**Supplements 4.2.3.A, B & C**)

The secondary practice approach is useful to help achieve the desired treatment credit when demand is not enough to sufficiently draw water levels in the tank down between storm events. Of course, if demand for the harvested rainwater is relatively high, then a secondary practice may not be needed or desired.

A secondary practice may be particularly useful to employ in sites that use captured rainwater for irrigation during part of the year, but have no other use for the water during non-irrigation months. During non-irrigation months, credit cannot be realized unless on-site infiltration/treatment or another drawdown mechanism creates a year-round drawdown, since no stormwater benefit would be realized during non-seasonal periods.

The design of the secondary practice should account for soil types, ground surface areas, release rates, methods of conveyance (gravity fed or pumped), time periods of operation, and invert elevations to determine the disposal rate and sizing of the practice (both storage volume and surface area).

RH-5. Materials Specifications

The basic material specifications for Rainwater Harvesting systems are presented in **Table RH-4**. Designers should consult with experienced Rainwater Harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated tanks and other system components.

Table RH-4. Design specifications for Rainwater Harvesting systems

Item	Specification
Gutters and Downspout	Materials commonly used for gutters and downspouts include polyvinylchloride pipe, vinyl, aluminum and galvanized steel. Lead should not be used as gutter and downspout solder, since rainwater can dissolve the lead and contaminate the water supply. ▪ The length of gutters and downspouts is determined by the size and layout of the catchment and the location of the storage tanks. ▪ Be sure to include needed bends and tees.
Pre-Treatment	At least one of the following (all rainwater to pass through pre-treatment): ▪ first flush diverter ▪ vortex filter ▪ roof washer ▪ leaf and mosquito screen (1 mm mesh size)
Storage Tanks	▪ Materials used to construct storage tanks should be structurally sound. ▪ Tanks should be constructed in areas of the site where native soils can support the load associated with stored water. ▪ Storage tanks should be water tight and sealed using a water-safe, non-toxic substance. ▪ Tanks should be opaque to prevent the growth of algae. ▪ Re-used tanks should be fit for potable water or food-grade products. ▪ Underground Rainwater Harvesting systems should have a minimum of 18 to 24 inches of soil cover and be located below the frost line. ▪ The size of the Rainwater Harvesting system(s) is determined during the design calculations.

Note: This table does not address indoor systems or pumps.

Table RH-5 compares the advantages and disadvantages of different storage tank materials.

4.2.8. Rainwater Harvesting (RH)

Table RH-5. Advantages and Disadvantages of Various Cistern Materials (Source: Cabell Brand Center, 2007; Cabell Brand Center, 2009)

Tank Material	Advantages	Disadvantages
Fiberglass	Commercially available, alterable and moveable; durable with little maintenance; light weight; integral fittings (no leaks); broad application	Must be installed on smooth, solid, level footing; pressure proof for below-ground installation; expensive in smaller sizes
Polyethylene	Commercially available, alterable, moveable, affordable; available in wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; must be painted or tinted for above-ground installations; pressure-proof for below- ground installation
Modular Storage	Can modify to topography; can alter footprint and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of water tight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (20 to 50 gallons); limited application
Galvanized Steel	Commercially available, alterable and moveable; available in a range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; must be lined for potable use; can only install above ground; soil pH may limit underground applications
Steel Drums	Commercially available, alterable and moveable	Small storage capacity; prone to corrosion, and rust can lead to leaching of metals; verify prior to reuse for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast in Place Concrete	Durable, immoveable, versatile; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; permanent; will need to provide adequate platform and design for placement in clay soils
Stone or concrete Block	Durable and immoveable; keeps water cool in summer months	Difficult to maintain; expensive to build

The images in Figures **RH-15** to **RH-17** display three examples of various materials and shapes of cisterns discussed in **Table RH-5** above.

Figure RH-15. Example of Multiple Fiberglass Cisterns in Series (Source: Rainwater Management Solutions)

Figure RH-16. Example of two Polyethylene Cisterns (Source: Rainwater Management Solutions)

Figure RH-17. Example of Modular Units (Source: Rainwater Management Solutions)

4.2.8. Rainwater Harvesting (RH)

RH-6. Design Adaptations

RH-6.1. Karst Terrain

Above-ground Rainwater Harvesting systems are a preferred practice in karst, as long as the rooftop surface is not designated as a stormwater hotspot.

RH-6.2. Steep Terrain

Rainwater Harvesting systems are ideal in areas of steep terrain as long as the tank or cistern itself is installed in a stable configuration (e.g., on a flat pad).

RH-6.3. Cold Climate & Winter Performance

Rainwater Harvesting systems can be used throughout the year if they are located underground or indoors to prevent problems associated with freezing, ice formation and subsequent system damage. Alternately, an outdoor system can be used seasonally, or year round if special measures and design considerations are incorporated. Outdoor Rainwater Harvesting systems have a number of components that can be impacted by freezing winter temperatures. Designers should give careful consideration to these conditions to prevent system damage and costly repairs.

For above-ground systems, winter-time operation may be more challenging, depending on tank size and whether heat tape is used on piping. If not protected from freezing, these Rainwater Harvesting systems must be taken offline for the winter and stormwater treatment credit may not be granted for the practice during that off-line period.

RH-6.4. Stormwater Retrofitting

Rainwater Harvesting is an excellent candidate for retrofitting, especially on sites where space is limited and/or where rooftops constitute a fairly high percentage of the site impervious cover. Retrofit considerations include design of the plumbing system where indoor use of harvested rainwater is envisioned, the type of existing roof material, conflicts with utilities for underground tanks, and space available for a downstream runoff reduction practice if needed to get a runoff reduction credit.

For more information on retrofitting, see the Center for Watershed Protection's manual, ***Urban Stormwater Retrofit Practices*** (Schueler et al., 2007).

4.2.8. Rainwater Harvesting (RH)

RH-7. Construction & Installation

RH-7.1. Construction Sequence

It is advisable to have a single contractor to install the Rainwater Harvesting system, outdoor irrigation system and secondary runoff reduction practices. The contractor should be familiar with Rainwater Harvesting system sizing, installation, and placement. A licensed plumber is required to install the Rainwater Harvesting system components to the plumbing system.

A standard construction sequence for proper Rainwater Harvesting system installation is provided below. This can be modified to reflect different Rainwater Harvesting system applications or expected site conditions.

- Choose the tank location on the site
- Route all downspouts or roof drains to pre-screening devices and first flush diverters

- Properly install the tank
- Install the pump (if needed) and piping to end-uses (indoor, outdoor irrigation, or tank dewatering release)
- Route all pipes to the tank
- Stormwater should not be diverted to the Rainwater Harvesting system until the overflow filter path has been stabilized with vegetation.

RH-7.2. Construction Inspection

The following items should be inspected prior to final sign-off and acceptance of a Rainwater Harvesting system:

- Rooftop area matches plans
- Diversion system is properly sized and installed
- Pretreatment system is installed
- Mosquito screens are installed on all openings
- Overflow device is directed as shown on plans
- Rainwater Harvesting system foundation is constructed as shown on plans
- Catchment area and overflow area are stabilized
- Secondary runoff reduction practice(s) installed as shown on plans

RH-8. Maintenance Criteria

RH-8.1. Maintenance Agreements

Section C.b.5.ii(C) of the MS4 General Permit requires a maintenance agreement and plan between the property owner or operator and the local program authority (for municipal separate storm sewer systems). This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

All Rainwater Harvesting systems must be covered by a drainage easement to allow inspection and maintenance. The easement should include the tank, the filter path and any secondary runoff reduction practice. If the tank is located in a residential private lot, its existence and purpose must be noted on the deed of record. Homeowners will need to be provided with a simple document that explains the purpose of the Rainwater Harvesting system and routine maintenance needs. Where legally binding maintenance agreements apply, they should specify the property owner's primary maintenance responsibility, require homeowners to pay to have their system inspected by a qualified third party inspector, and authorize the qualifying local program staff to access the property for inspection or corrective action in the event this is not done.

RH-8.2. Maintenance Inspections

All Rainwater Harvesting systems components should be inspected by the property owner in the spring and fall each year. A comprehensive inspection by a qualified third party inspector should occur every third year. Example maintenance checklists for Rainwater Harvesting systems can be found in Appendix A of this Manual.

RH-8.3. Rainwater Harvesting System Maintenance Schedule

Maintenance requirements for Rainwater Harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. Table RH-6 describes routine maintenance tasks to keep Rainwater Harvesting systems in working condition.

Table RH-6. Suggested maintenance tasks for Rainwater Harvesting systems

Activity	Frequency
Keep gutters and downspouts free of leaves and other debris	O: Twice a year
Inspect and clean pre-screening devices and first flush diverters	O: Four times a year
Inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately	O: Once a year
Inspect condition of overflow pipes, overflow filter path and/or secondary runoff reduction practices	O: Once a year
Inspect tank for sediment buildup	I: Every third year
Clear overhanging vegetation and trees over roof surface	I: Every third year
Check integrity of backflow preventer	I: Every third year
Inspect structural integrity of tank, pump, pipe and electrical system	I: Every third year
Replace damaged or defective system components	I: Every third year

Key: O = Owner I = qualified third party inspector

RH-8.4. Mosquitoes

In some situations, poorly designed Rainwater Harvesting systems can create habitat suitable for mosquito breeding and reproduction. Designers should provide screens on above- and below-ground tanks to prevent mosquitoes and other insects from entering the tanks. If screening is not sufficient in deterring mosquitoes, dunks or pellets containing larvicide can be added to cisterns when water is intended for landscaping use.

RH-8.5. Cold Climate Considerations

At the start of the winter season, vulnerable above-ground systems that have not been designed to incorporate special precautions from freezing should be disconnected and drained. It may be possible to reconnect the former roof leader systems for the winter.

For underground and indoor systems, downspouts and overflow components should be checked for ice blockages during snowmelt events.

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Supplement 4.2.8.A

Description of the Cistern Design Spreadsheet & Inputs

The Cistern Design Spreadsheet uses daily rainfall records and an accounting of inputs and outflow in a continuous model to calculate the runoff reduction volume associated with 1 inch of rainfall. The spreadsheet is a design tool for Rainwater Harvesting, but is also used to derive the runoff reduction credit used in the Design Compliance Spreadsheet for compliance with the 1-inch on-site retention standard.

Water Contributions & Losses to the System

A runoff coefficient of 0.95 for rooftop surfaces and a filter efficiency rate of 95% for the 1-inch storm are assumed. It is assumed that filters are to be installed on all systems and that the first flush diversion is incorporated into the filter efficiency. The remaining precipitation is then added to the water level that existed in the cistern the previous day, with all of the total demands subtracted on a daily basis. If any overflow is realized, the volume is quantified and recorded. If the tank runs dry (reaches the cut-off volume level), then the volume in the tank is fixed at the low level and a dry-frequency day is recorded. The full or partial demand met in both cases is quantified and recorded. A summary of the water balance for the system is provided below.

Water Contribution:

- **Precipitation to rooftop.** The volume of water contributing to the Rainwater Harvesting system is a function of the rainfall and rooftop area captured, as defined by the designer.
- **Municipal Backup (optional).** In some cases, the designer may choose to install a municipal backup water supply to supplement tank levels. Note that municipal backups may also be connected post-tank (i.e. a connection is made to the non-potable water line that is used for pumping water from the tank for reuse), thereby not contributing any additional volume to the tank.

Water Losses:

- **Rooftop Runoff Coefficient (Rv).** The rooftop is estimated to convey 95% of the rainfall that lands on its surface (i.e., Rv = 0.95).
- **First Flush Diversion.** The first 0.02 to 0.06 inches of rainfall directed to filters is diverted from the system in order to prevent clogging with debris. This value is assumed to be contained within the filter efficiency rate.
- **Filter Efficiency.** Each filter has an efficiency curve associated with the rate of runoff and the size of the storm it will receive from a rooftop. It is assumed that, after the first flush diversion and loss of water due to filter inefficiencies, the remainder of the 1-inch storm will be successfully captured. A minimum of 95% of the runoff from a 1-inch storm must be able to pass through the filter and be conveyed into the tank. Some localities may also require a minimum filter efficiency for a larger storm event (e.g. minimum 90% filter efficiency for 2 or 10-year storm), depending on design objectives and local review agency policy. For the purposes of selecting an appropriately sized filter, a rainfall intensity of 1-inch/hour should be used for the 24 hour, 1-inch storm. The local rainfall intensity values for the 2 and 10 year storms should be used when designing for flood control/detention volumes, if required by the local program.
- **Drawdown (Design Volume, Dv).** This is the stored water within the cistern that is reused or directed to a secondary runoff reduction practice. It is the volume of runoff that is reduced from the rooftop drainage area. This is the water loss that translates into the Runoff Reduction Volume credit in the Site Compliance Spreadsheet. The Runoff Reduction Volume credit is the volume reduction that is achieved toward reducing the 1" reduction performance standard in the MS4 General Permit (see **Chapter 3** of the Manual).
- **Overflow.** For the purposes of addressing the Dv, orifice outlets for both detention and emergency overflows are treated the same. This is the volume of water that may be lost during large storm events or successive precipitation events.

Spreadsheet Inputs

The spreadsheet model requires the following user inputs, as applicable:

Regional location. Indicate the region that is closest to where the practice is being installed. Rainfall data associated with that region will automatically provide the relevant precipitation data for the design storm for that area.

Roof area. The user must estimate the total rooftop area that will be captured for contribution to the system; this, combined with the target storm (1 inch of rainfall), yields the volume of rooftop runoff to be managed.

Irrigation use. The user must supply the total pervious area (in square feet) that will be irrigated; the spreadsheet will automatically calculate the demand based on a 1-inch per week watering during the appropriate season, unless the user specifies a different watering rate. The user can enter a start date and an end date in the year to specify the irrigation season (e.g., March 30 to September 1). If an on-site infiltration system is designed, the lesser drawdown rate (irrigation or on-site infiltration during the off-season) must be used to quantify the Runoff Reduction volume credit.

Indoor demand. The user then needs to define the parameters relating to indoor use of water, if rainwater is intended for such purposes. If specific daily water demand has been calculated for the indoor uses, those values can be entered directly into the spreadsheet (dark blue cells). Otherwise, the spreadsheet will automatically calculate the demand according to the following criteria and inputs:

- Flushing Toilets/Urinals – The user enters the average number of people that use the building within a day, the days on which the building is regularly used within a week, and the number of hours the building is usually used during a day. The user also enters the gallons of water used per flush by urinals and toilets in the building (default set at 0.8 and 1.6 gallons, respectively). The spreadsheet calculates demand, based on three flushes per person per day.
- Laundry – The user enters the number of loads of laundry done per day, the average water use for each load of laundry, and the days of the week on which laundry is done. If a household only does 2 loads of laundry per week, for example, the user could specify that 1 load is done per day and laundry is done only Monday through Tuesday. The spreadsheet calculates average daily demand for laundry water based on these values.

Additional Daily Use. The user may enter an additional demand, such as bus or fire truck washing, street sweeper filling, etc.

Chilled Water Cooling Towers. The user may enter a quantity of water that will be needed for use in chilled water cooling towers.

Secondary Runoff Reduction Practice Drawdown. A cell is provided to enter an additional drawdown for secondary runoff reduction practices linked to the Rainwater Harvesting system, if applicable. The permissible flow to be directed is dependent upon the storage volume and surface area of the receiving secondary practice, and shall be based on the capacity of the secondary practice to store, infiltrate, and/or filter the flow coming to it. The secondary practice must be considered "part of" the rainwater harvesting system to utilize this slow-release drawdown option and must not be 'double-counted' elsewhere as an additional BMP.

Initial Abstraction. This is an optional input and provided as a mechanism for users that would like to specify an additional abstraction of the amount of rainwater that can be captured from the roof. This may be associated with roof material texture, conveyance, obstructions, etc. For reference: for CN = 98, Ia = 0.041"; for CN = 95, Ia = 0.105"; for CN = 90, Ia = 0.222".

First Flush Filter Diversion and Efficiency. The user enters the efficiency of the rainwater system's pre-treatment filter(s) associated with a 1-inch storm. Although this filter efficiency value can be defined by the user, the value must be 95% or higher to achieve Runoff Reduction Credit.

See Supplement 4.2.8.B for step-by-step guidance on using the spreadsheet.

Results for all Precipitation Events

The performance results of the Rainwater Harvesting system for all days during the entire period modeled, including the full spectrum of precipitation events, is included in the "Results" tab. This tab is not associated with determining the Runoff Reduction Volume Credit, but rather may be a useful tool in assisting the user to realize the performance of the various Rainwater Harvesting system sizes with the design parameters and demands specified.

- **Overflow Frequency.** This is a metric of both overflow frequency and average volume per year for the full spectrum of rainfall events. This will inform the user regarding the design parameters and magnitude of demand and associated performance of the system. If the system overflows at a high frequency, then the designer may want to increase the size of the cistern, decrease the rooftop area captured, or consider other mechanisms that could increase drawdown (e.g. increase the area to be irrigated, incorporate or increase on-site infiltration, etc.).
- **Dry Frequency.** Another useful measure is the dry frequency. If the cistern is dry a substantial portion of the time, this measure can inform the user that he/she may want to decrease the size of the cistern, decrease the demand on the system or explore capturing more rooftop area to provide a larger supply, if feasible. It can also provide useful insight for the designer to determine whether he/she should incorporate a backup water supply to ensure sufficient water supply through the system at all times.
- **Demand Met.** This is where the water demand met for various size cisterns and rooftop area/demand scenarios is reported. The Water Supply Chart in this tab displays the percentage of demand met by various cistern storage sizes. Normally, this graph assists the user in understanding the relationship between cistern sizes and optimal/diminishing returns. An example is provided in **Figure RH-18**.

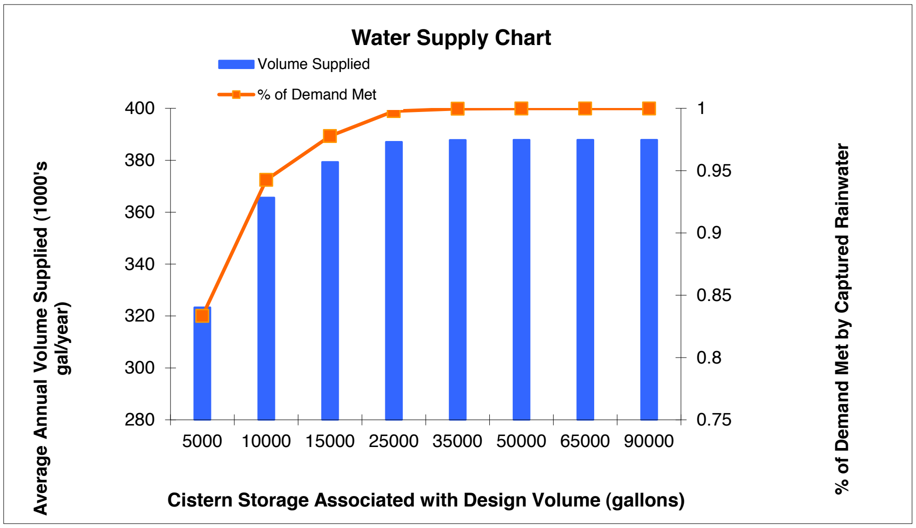

Figure RH-18. Percent Demand Met Vs. Cistern Storage Volume/Size

At some point, larger cisterns no longer provide significant increases in percentages of demand met. Conversely, the curve informs the user when a small increase in cistern size can yield a significant increase in the percentage of water demand that is met.

- **Inter-relationships and Curves of Diminishing Returns.** Plotting various performance metrics against one another can be very informative and reveal relationships that are not otherwise evident. One such inter-relationship is the number of dry days versus overflow frequency, depicted on the same graph. A range of cistern sizes tends to emerge, informing the designer where a small increase or decrease in tank size can have a significant impact on dry frequency and overflow frequency. Conversely, outside this range, changes in cistern sizes would yield small changes to dry frequency and overflow frequency, yet yield a large trade-off compared to the cost of the Rainwater Harvesting system.

Results for Precipitation Events of 1 Inch or Less

The amount of rooftop runoff volume that the tank can capture and use or draw down for all precipitation events of 1 inch or less is also quantified and recorded. These results are presented on the "Results-RR Volume Credit" tab. This information is used to calculate the Runoff Reduction Volume Credit, which is used as an input to the **Design Compliance Spreadsheet**.

- **Runoff Reduction Volume Credit.** A series of Runoff Reduction Volume Credit values are calculated for multiple sizes of cisterns. A trade-off curve plots these results, which allows for a comparison of the credit earned versus cistern size. While larger tanks yield more credit, they are more costly. The curve assists the user to choose the appropriate tank size, based on the design objectives and site needs, as well as to understand the rate of diminishing returns.
- **Overflow Volume** The frequency of cistern overflows and the average annual volume of the overflows resulting from precipitation events of 1 inch or less are also reported in this tab. A chart of the overflow frequency and overflow volume is provided. An example is shown below in **Figure RH-19**.

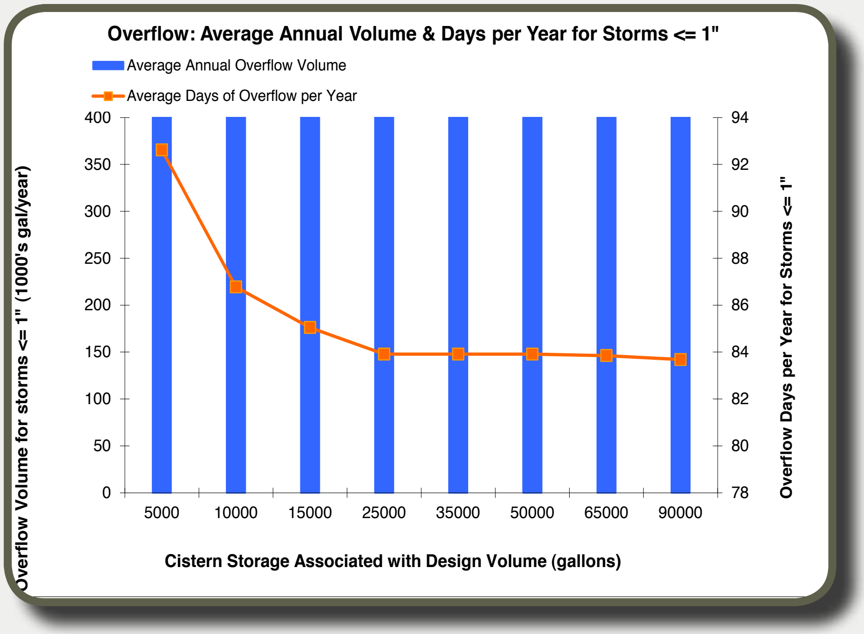

Figure RH-19. Overflow Volume and Frequency (for Storms <= 1") Vs. Cistern Storage Volume

Results from Cistern Design Spreadsheet to be transferred to Design Compliance Spreadsheet

There are two results from this Cistern Design Spreadsheet that are to be transferred to the Design Compliance Spreadsheet, as follows:

1. **Runoff Reduction Volume Credit:** Once the cistern storage volume has been selected, simply transfer the associated Runoff Reduction credit percentage into the Design Compliance Spreadsheet column called "% Credit" in the "Rainwater Harvesting" row in the blue cell.
2. **Contributing Drainage Area:** Enter the rooftop area that was used in the Cistern Design Spreadsheet in the same row into the "Impervious Cover in Contributing Drainage Area (acres)" column in the blue cell.

Completing the Sizing Design of the Cistern

Consider the following volume requirements when selecting a final cistern size.

1. **Low Water Cutoff Volume (Included).** A dead storage area must be included so that the pump will not run the tank dry. This volume is included within the Cistern Design Spreadsheet modeled volume.

2. **Cistern Storage Associated with Design Volume (Included).** This is the volume that was designed for using the Cistern Design Spreadsheet.
3. **Adding Locally-Required Stormwater Detention Volumes (Optional).** Additional detention volume may be added above and beyond the cistern storage associated with the Dv. Typical routing software programs may be used to design for this additional volume.
4. **Adding Overflow and Freeboard Volumes (Required).** An additional volume above the emergency overflow must be provided in order for the tank to allow very large storms to pass. Above this overflow water level will be an associated freeboard volume. This volume must account for a minimum of 5% of the overall tank size; however, sufficient freeboard should be verified for large storms. These volumes need to be added to the overall size of the cistern tank.

Supplement 4.2.8.B

Step-By-Step Instructions for Using the Cistern Design Spreadsheet

Tab 1: INPUT

1. Select a Region in the drop down menu that is located closest to the proposed site.
2. Enter the rooftop area to be captured and routed to the cistern (square feet).
3. Enter the Irrigation data, as described in Supplement 4.2.8.A (Spreadsheet Inputs) of this design specification.
4. Enter the Indoor Demand – Flushing toilets/urinals, as described in Supplement 4.2.8.A.
5. Enter the Indoor Demand – Laundry, as described in Supplement 4.2.8.A.
6. Enter and Additional Daily Uses (gallons per day).
7. Enter the amount that will be used for Chilled Water Cooling Towers (gallons per day).
8. Enter the On-Site infiltration design drawdown rate (gallons per day).
9. Enter an Initial Abstraction value (inches), if desired.
10. Enter the filter efficiency percentage for the 1-inch storm at a 1-inch/hour intensity. A minimum of 95% must be achieved. However, if the filter achieves a higher efficiency rate, this higher value can be entered.

Tab 2: JULIAN DAY CALENDAR

This tab is included for assistance in selecting a start date and end date for various water uses shown in Tab 1. The day of the year should be selected according to the Julian day dates specified in this tab.

Tab 3: RESULTS – RR VOLUME CREDIT

11. Select the Results – Runoff Reduction Volume Credit tab to view modeling results for the 1-inch storm.
12. Observe the results for the Runoff Reduction Volume Credit highlighted in the far right column of the table, as it relates to the cistern storage volume. If this credit is much higher or lower than design objectives for many of the cistern storage sizes, the input values should be assessed to determine if the demand can be increased or decreased.

Tab 4: RESULTS

13. Select the Results tab to view the modeling results for all storm events.
14. Observe the results for overflow frequency, dry frequency and percent of demand met by rainwater.
15. If the demand met for a particular storage size is adequate, observe the dry frequency, overflow frequency and Runoff Reduction Volume Credit. If these parameters meet design objectives and balance trade-offs reasonably

well, move to the next step. If any of the resulting performance values are not acceptable design objectives, then re-visit the input spreadsheet to assess whether lower or higher demands can be achieved (e.g. decrease/increase in irrigation frequency; increase/decrease in the rooftop area captured, if feasible; etc.).

RESULT TO BE TRANSFERRED TO RUNOFF REDUCTION SPREADSHEET

16. **First Value to Transfer:** Once the cistern storage volume and its associated Runoff Reduction Volume Credit has been selected, simply transfer that credit amount into the Design Compliance Spreadsheet. Enter it into the column called "Credit," in the appropriate cell.
17. **Second Value to Transfer:** Then enter the rooftop area that was used in the same row and in the Cistern Design Spreadsheet into the "Credit Area (acres)" column in the blue cell.

Supplement 4.2.8.C

Notes Regarding the Cistern Design Spreadsheet Methodology

If a rainwater use is only seasonal (e.g. summer irrigation), the spreadsheet sets the input for that use to zero for the purpose of calculating the Runoff Reduction Volume (RRv) credit. However, this does not apply if a secondary runoff reduction practice is designated to infiltrate/treat an equivalent volume of rainwater.

With each documented daily use, the runoff volume is reduced. The RRv credit is a percentage equivalent to the sum of all the stored rainwater that is used/infiltrated during a 30 year period, divided by the entire volume that is generated during that same period for all precipitation events of 1-inch or less. That is:

$$Tv\% = \frac{\sum_{i=1}^{n} Vu}{\sum_{i=1}^{n} Tv}$$

Where:

$$\sum_{i=1}^{n} Tv = \sum_{i=1}^{n} \left[Pi \times SA \times Rv \times \left(\frac{1\ ft}{12\,in} \right) \times \left(\frac{7.48\,gallons}{1\,cf} \right) \right]$$

And

$$\sum_{i=1}^{n} Vu = \sum \left[Tv - ff - Ov \right]$$

NOTE: This is the total volume of runoff that has been removed from the runoff for storms of 1 inch or less for the entire 30 year period. It is calculated adding the contribution all precipitation of 1 inch or less, times the runoff coefficient, minus the first flush diversion, minus the overflow.

ff = First flush diversion and filter overflow due to filter inefficiency
Ov = Overflow from precipitation events of 1 inch or less
Rv = Runoff Coefficient of the rooftop = 0.95
Pi = Precipitation of 1 inch or less (inches)
SA = Surface area of the rooftop that is captured and conveyed to the cistern (sq. ft.)
i = Start day of modeling (first day modeled in 1977)
n = End day of modeling (Last day modeled in 2007)
Tv = Treatment Volume of the cistern, assuming the Tv applies to a drainage area that is only the rooftop draining to the system.

The spreadsheet calculations should always be included with the stormwater management submittal package for local plan review. See **Supplement 4.2.8.D** for more information on recommended submittal package items.

Supplement 4.2.8.D

Plan Submittal Recommendations

It is highly recommended that designers of Rainwater Harvesting systems coordinate design efforts and communicate intent to both site designers and building architects, since a Rainwater Harvesting system links the building to the site. The effectiveness of such a system, in terms of use for demand and as a stormwater management tool, is also highly dependent on the efficiency of capturing and conveying rainwater from the building rooftop to the storage tank.

The following lists are items that plan reviewers may want to recommend and/or require for submittals of Rainwater Harvesting systems being used as a stormwater management tool:

A. Incorporation of Rainwater Harvesting system into site plan grading and storm sewer plan construction documents, as follows:

1. Include a roof plan of the building that will be used to capture rainwater, showing slope direction and roof material.
2. Include a detail or note specifying the minimum size, shape configuration, and slope of the gutter(s) that convey rainwater to the tank.
3. Display downspout leaders from the rooftops being used to convey rainwater.
4. Display the pipe layout (pipes between downspouts and the tank and between tank and points of use) in plan view, specifying materials, diameters, slopes and lengths, to be included on typical grading and utilities or storm sewer plan sheets.
5. Specify location and dimensions of outlet protection, adequate receiving channel, and/or receiving storm drain for overflow from storage tank.

B. Rainwater Harvesting system construction document sheet, to show the following:

1. The cistern/tank or storage unit material and dimensions in a scalable detail (use a cut sheet detail from manufacturer, if appropriate).
2. Include the specific filter performance specification and filter efficiency curves. Runoff estimates from the rooftop area captured for 1-inch storm should be estimated and compared to filter efficiencies for the 1-inch storm. It is assumed that the first flush diversion is included in filter efficiency curves. A minimum of 95% filter efficiency should

be met for the Runoff Reduction volume credit. If this value is altered (increased) in the Cistern Design Spreadsheet, the value should be reported. Filter curve cut sheets are normally available from the manufacturer.

3. Include elevation of pump intake point and low water cut-off level in tank.
4. Show the specified materials and diameters of inflow and outflow pipes.
5. Show the inverts of the inlets, drawdown orifice (if applicable), outlets, the emergency overflows, and, if applicable, the receiving secondary runoff reduction practice.
6. Show the incremental volumes specified for: (a) the low water cut-off volume level; (b) the storage volume associated with the Runoff Reduction volume credit; (c) the storage volume associated with the Channel Protection Volume (if applicable); (d) the storage volume associated with the Flood Protection Volume (if applicable); and (e) the overflow freeboard volume.
7. Include a cross section of the storage unit displaying the inverts associated with the various incremental volumes (if requested by the reviewer).

C. Supporting Calculations and Documentation

1. Provide a drainage area map delineating the rooftop area (square feet) to be captured and indicating the 1-inch storm, 1 year storm and 10 year storm peak discharge values on the plan (11x17 is sufficient).
2. Provide calculations showing that the gutter, at its specified size and slope, will convey the design storm specified by regulatory authority.
3. Provide calculations showing that the roof drains, at their specified size, slope and material, will convey the design storm specified by regulatory authority.
4. Cistern Design Spreadsheet: a print-out of the "Input" tab, as modeled.
5. Cistern Design Spreadsheet: a print-out of the "Results - Runoff Reduction Volume Credit" tab, as modeled.
6. Cistern Design Spreadsheet: a printout of the "Results" tab, as modeled.

D. Stormwater Management Forms

1. The owner should treat a Rainwater Harvesting system as he/she would treat any other stormwater management facility. If a stormwater management maintenance agreement form is required by the jurisdiction, then the same form should be submitted for a Rainwater Harvesting system.
2. An agreement form or note on the plans should be included to ensure that the minimum demand that was specified in the stormwater management plan submittal documents is being met. Likewise, if the property (and Rainwater Harvesting system) is transferred to a different owner, the new owner must be held responsible to ensure the system will continue to archive the specified year-round drawdown. If the year-round drawdown is not being met as specified, an alternative stormwater management plan may be required.

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VR-1. Introduction

Source: WV DEP

Vegetated Roofs (also known as green roofs, living roofs or ecoroofs) are alternative roof surfaces that capture and store rainfall in an engineered growing media designed to support plant growth.

Vegetated Roofs can be used to:

- Manage the first one inch of rainfall on-site
- Meet partial storage requirements for local stormwater detention standards
- Retrofit existing developed areas, especially ultra-urban sites
- Vegetated Roofs DO NOT achieve additional pollutant removal credit beyond that achieved by the volume reduction credit.

A portion of the rainfall captured on a Vegetated Roof evaporates or is taken up by plants, which helps reduce runoff volumes and peak runoff rates on development sites. Vegetated Roofs typically contain a layered system of roofing, which is designed to support plant growth and retain water for plant uptake while preventing ponding on the roof surface. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer toward the roof drain outlets.

There are two different types of Vegetated Roof systems: ***Intensive Vegetated Roofs*** have a deeper growing media layer that ranges from 6 inches to 4 feet thick, which is planted with a wider variety of plants, including trees. ***Extensive Vegetated Roofs*** have shallower growing media (4 inches), which is planted with carefully selected drought tolerant vegetation. Extensive Vegetated Roofs are much lighter and more commonly applied as stormwater management features. While intensive roofs have a deeper growing media and therefore more potential storage volume, they are not credited with greater volume reductions. However, they may provide other ancillary building life-cycle cost benefits, such as heating and cooling.

Vegetated Roofs are typically not designed to provide stormwater detention of larger storms (e.g., 2-yr, 15-yr).

Figure VR-1 illustrates several Vegetated Roof applications. **Figure VR-2** is a typical schematic, and **Figure VR-3** shows typical layers of a Vegetated Roof system. **Tables VR-1 and VR-2** describe the runoff reduction and pollutant removal performance of Vegetated Roofs. **Table VR-3** is a design checklist to help guide the design process for Vegetated Roofs.

4.2.9. Vegetated Roofs (VR)

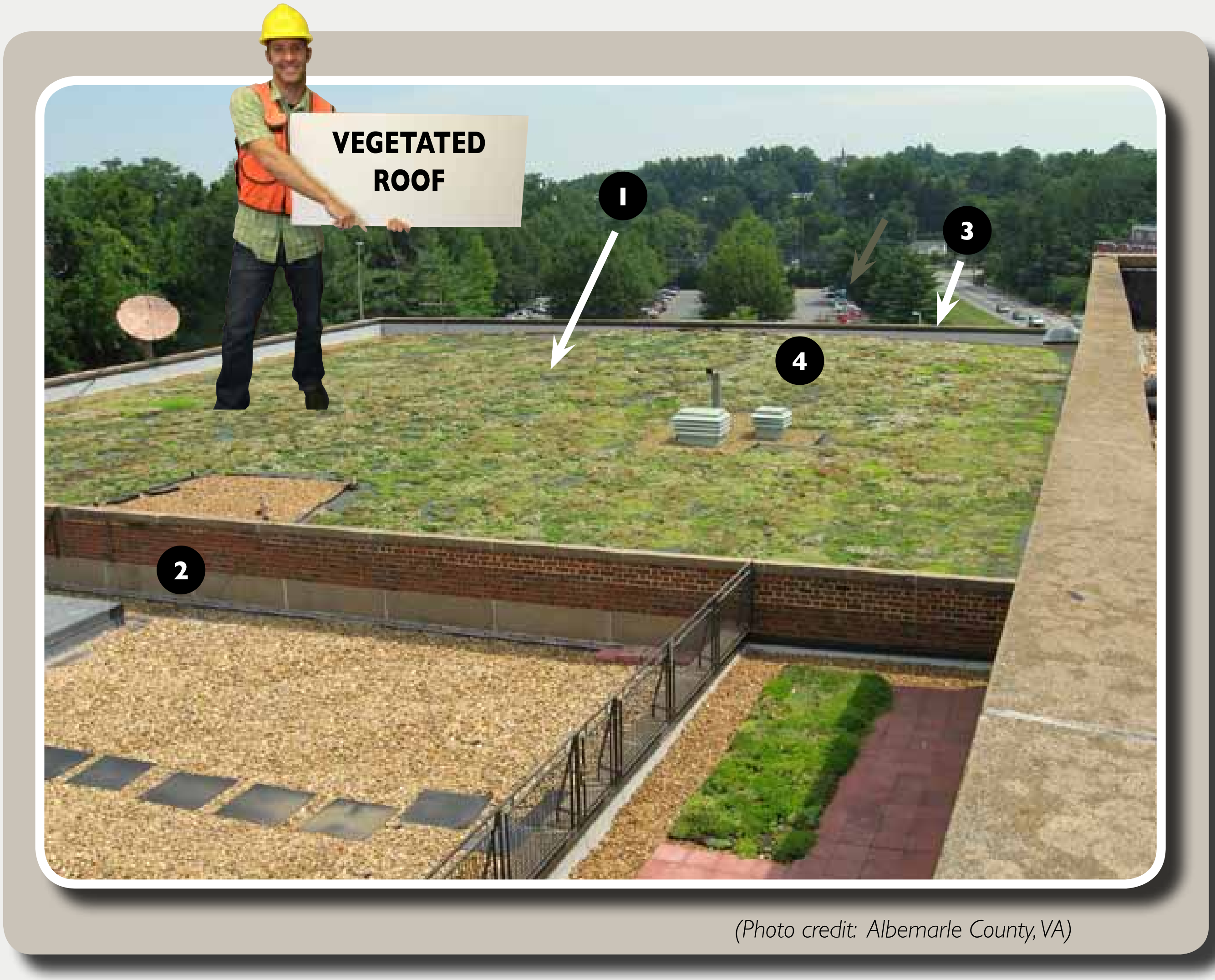
VR-1.1. Planning the Practice

Figure VR-1. Example Applications of Vegetated Roofs

Extensive Vegetated Roof (Source: WVDEP)

Intensive Vegetated Roof (Source: University of Virginia)

Figure VR-2. Schematic of typical Vegetated Roof



(Photo credit: Albemarle County, VA)

1. **Elements of Vegetated Roof** – Figure VR-2 & Section VR-4.1
2. **Structural capacity of roof** – Section VR-4.3
3. **Roof drains/overflow** – Section VR-4.5
4. **Plant selection** – Section VR-4.6

VR-1.2. Vegetated Roof Design Options & Performance

Table VR-1 describes the design options for a Vegetated Roof and the associated performance in terms of reducing the volume associated with one inch of rainfall on the site. There is only one design level for a Vegetated Roof. **Table VR-2** summarizes the Total Pollutant Load Reduction for Vegetated Roof designs for the purposes of calculating site-based pollutant load reductions in the context of Total Maximum Daily Loads (TMDLs) and/or watershed plans.

The runoff reduction credit for Vegetated Roof is provided in **Table VR-1**. There is only one design level for this practice. As shown in **Table VR-2**, there is no corresponding pollutant removal credit for Vegetated Roofs.

Table VR-1. Vegetated Roof Design Levels: Descriptions & Performance

Design Level	Design Variation Descriptions	Applications	Performance Achieved Toward Reducing 1" of Rainfall
One Design Level	Standard Design[1] • Soil media ≥ 4" • No more than 20% organic matter	Well-suited to ultra-urban areas and retrofits.	100% volume reduction for the Design Volume of the practice[2]

[1] *All designs must be in conformance with ASTM international standards for Vegetated Roofs referenced in* **Section VR-5**.
[2] *The Design Volume includes the storage volume of the growing media as defined by the porosity of the media (usually 0.25 to 0.35) and the media depth. Additional volume reduction credit is not provided for oversized (deeper) media storage.*

Table VR-2. Total Pollutant Load Reduction1 Performance Values for Vegetated Roofs

Design Level	Total Suspended Solids (TSS)	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)
One Design Level	TSS = 70%	TP = 45% TN = 45%

[1] *Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008). Vegetated Roofs do not achieve pollutant removal; therefore the Total Pollutant Load Reduction is solely a function of volume reduction. The runoff reduction credit awarded in Table 1 corresponds to a 45% annual pollutant load reduction for nutrients, and 70% for TSS.*

VR-1.3. Vegetated Roof Design Checklist

Table VR-3. Vegetated Roof Design Checklist

CHECKLIST

This checklist will help the designer with the necessary design steps for Vegetated Roofs.

- ☐ Check feasibility for site and building– **Table VR-1 and Section VR-3**
- ☐ Complete Design Compliance Spreadsheet to plan and confirm required Vegetated Roof sizing (Design Volume), additional practices needed, and overall site compliance – Design Compliance **Spreadsheet & Chapter 3 of Manual**
- ☐ Check Vegetated Roof sizing guidance and make sure the building has adequate structural capacity – **Sections VR-4.2 and VR-4.3**
- ☐ Check design adaptations appropriate to the site – **Section VR-6**
- ☐ Design Vegetated Roof in accordance with design criteria and typical details – **Sections VR-2 & VR-4**
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence notes

4.2.9. Vegetated Roofs (VR)

VR- 2. Typical Details

The typical layers of a Vegetated Roof are shown in **Figure VR-3**.

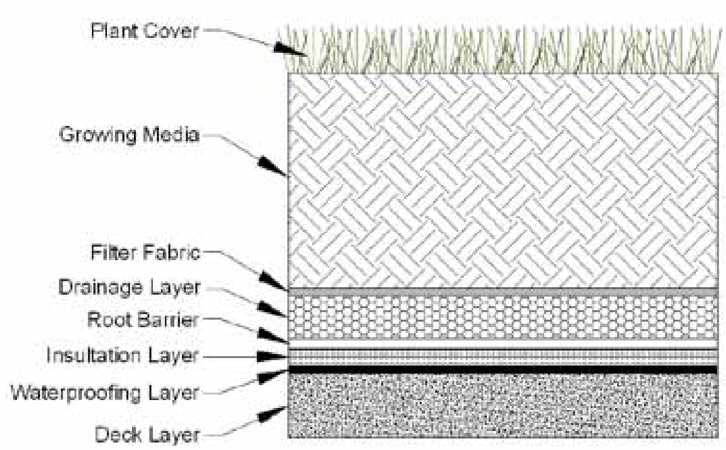


Figure VR-3. Typical Layers for a Vegetated Roof

4.2.9. Vegetated Roofs (VR)

VR-3. Feasibility Criteria and Design Considerations

Vegetated Roofs are ideal for use on commercial, institutional, municipal and multi-family residential buildings. They are particularly well-suited for use on ultra-urban development and redevelopment sites. Key constraints with Vegetated Roofs include the following:

Structural Capacity of the Roof. When designing a Vegetated Roof, designers must not only consider the stormwater storage capacity of the Vegetated Roof, but also its structural capacity to support the weight of the additional water. A conventional rooftop typically must be designed to support an additional 15 to 30 pounds per square foot (psf) for an extensive Vegetated Roof. As a result, a structural engineer, architect or other qualified professional should be involved with all Vegetated Roof designs to ensure that the building has enough structural capacity to support a Vegetated Roof. See Section VR-4.3, Structural Capacity for more information on structural design considerations.

Roof Pitch. Vegetated Roof storage volume is maximized on relatively flat roofs (a pitch of 1 to 2%). Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growing media. Vegetated Roofs can be installed on rooftops with slopes up to 25% if baffles, grids, or strips are used to prevent slippage of the media. These baffles should be designed to ensure the roof provides adequate storage for the design storm.

Roof Access. Adequate access to the roof must be available to deliver construction materials and perform routine maintenance. Roof access can be achieved either by an interior stairway through a penthouse or by an alternating tread device with a roof hatch or trap door not less than 16 square feet in area and with a minimum dimension of 24 inches (NVRC, 2007). Designers should also consider how they will get construction materials up to the roof (e.g., by elevator or crane) and how construction materials will be stockpiled in the confined space.

Roof Type. Vegetated Roofs can be applied to most roof surfaces, although concrete roof decks are preferred. Certain roof materials, such as exposed treated wood and uncoated galvanized metal, may not be appropriate for Vegetated Roofs due to pollutants leaching through the media (Clark et al, 2008).

Setbacks. Vegetated Roofs should not be located near rooftop electrical and HVAC systems. A 2-foot wide vegetation-free zone is recommended along the perimeter of the roof, with a 1-foot vegetation-free zone around all roof penetrations, to act as a firebreak. The 2-foot setback may be relaxed for small or low Vegetated Roof applications where parapets have been properly designed.

Local Building Codes. Building codes often differ in each municipality, and local planning and zoning authorities should be consulted to obtain proper permits. In addition, the Vegetated Roof design should comply with local building codes with respect to roof drains and emergency overflow devices.

4.2.9. Vegetated Roofs (VR)

VR-4. Design Criteria

VR-4.1. Functional Elements of a Vegetated Roof System

A Vegetated Roof is composed of up to eight different systems or layers, from bottom to top, that are combined together to protect the roof and maintain a vigorous cover (see **Figure VR-3**). Designers can employ a wide range of materials for each layer, which can differ in cost, performance, and structural load. The entire system as a whole must be assessed to meet design requirements. Some manufacturers offer proprietary Vegetated Roof systems that arrive at the project fully assembled, including plants. Alternatively, the designer or architect must specify and assemble all the Vegetated Roof system components. Several notable resources for assembling the components of a Vegetated Roof system include Weiler and Scholz-Barth (2009), Snodgrass and Snodgrass (2006), and Dunnett and Kingsbury (2004).

Vegetated Roof design layers include:

1. **Deck Layer:** The roof deck layer is the foundation of a Vegetated Roof. It may be composed of concrete, wood, metal, plastic, gypsum or a composite material. The type of deck material determines the strength, load bearing capacity, longevity and potential need for insulation in the Vegetated Roof system. In general, concrete decks are preferred for Vegetated Roofs, although other materials can be used as long as the appropriate system components are matched to them.
2. **Waterproofing Layer:** All Vegetated Roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. A wide range of waterproofing materials can be used, including built up roofs, modified bitumen, single-ply, and liquid-applied methods (see Weiler and Scholz-Barth, 2009 and Snodgrass and Snodgrass, 2006). The waterproofing layer must be 100% waterproof and have an expected life span as long as any other element of the Vegetated Roof system.
3. **Insulation Layer:** Many Vegetated Rooftops contain an insulation layer, usually located above, but sometimes below, the waterproofing layer. The insulation increases the energy efficiency of the building and/or protects the roof deck (particularly for metal roofs). According to Snodgrass and Snodgrass (2006), the trend is to install insulation on the outside of the building, in part to avoid mildew problems.
4. **Root Barrier:** The next layer of a Vegetated Roof system is a root barrier that protects the waterproofing membrane from root penetration. A wide range of root barrier options are described in Weiler and Scholz-Barth (2009). Chemical root barriers or physical root barriers that have been impregnated with pesticides, metals or other chemicals that could leach into stormwater runoff should be avoided.
5. **Drainage Layer and Drainage System:** A drainage layer is then placed between the root barrier and the growing media to quickly remove excess water from the vegetation root zone. The selection of the drainage layer type and thickness is an important design decision that is governed by the required conveyance capacity and the structural capacity of the rooftop. The depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive Vegetated Roof systems. The drainage layer should consist of synthetic or inorganic materials, such as a 1-2 inch layer of clean, washed granular material [American Society for Testing and Materials (ASTM) D 448 size No. 8 stone or lightweight granular mix], or recycled polyethylene that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors and roof leaders. ASTM E2396 and E2398 can be used to evaluate alternative material specifications.
6. **Root-Permeable Filter Fabric:** A semi-permeable polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it.
7. **Growing Media:** The next layer in an extensive Vegetated Roof is the growing media, which is typically 3 to 6 inches deep. The recommended growing media for extensive Vegetated Roofs is composed of approximately 80% to 90% lightweight inorganic materials, such as expanded slates, shales or clays, pumice, scoria or other similar materials. The remaining media should contain no more than 20% organic matter, normally well-aged compost (see Appendix D). The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. More information on growing media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006).

   The composition of growing media for intensive Vegetated Roofs may be different, and it is often much greater in depth (e.g., 6 to 48 inches). If trees are included in the Vegetated Roof planting plan, the growing media must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees.

8. **Plant Cover:** The top layer of a Vegetated Roof consists of non-native, slow-growing, shallow-rooted, perennial, succulent plants that can withstand harsh conditions at the roof surface. Guidance on selecting the appropriate

Vegetated Roof plants for hardiness zones in West Virginia can be found in Snodgrass and Snodgrass (2006). A mix of base ground covers (usually Sedum species) and accent plants can be used to enhance the visual amenity value of a Vegetated Roof. See Section VR-4.6 for additional plant information.

VR-4.2. Overall Sizing

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a BMP plan:

Target Treatment Volume (Tv) = Volume associated with managing 1" of rainfall based on the size and land cover of the contributing drainage area (CDA), as determined by the Design Compliance Spreadsheet. Any given best management practice (BMP) may treat the full Tv or only part of it if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on storage within different layers as prescribed in the BMP specification. For Vegetated Roofs, Dv will equal Tv if the CDA is limited to the rooftop itself. However, if the Vegetated Roof is used in conjunction with downstream runoff reduction practices, the Dv of the Vegetated Roof will be a subset of the overall drainage area Tv. In such cases, the sum of the Design Volume in the Vegetated Roof plus that of the other practices in the treatment train should equal the total drainage area Tv.

See **Chapter 3** for more information on the runoff reduction design methodology.

For the purposes of this sizing section, the sizing relates to the Dv of the permeable pavement being designed.

The minimum 4-inch depth and the porosity of the growing media define the storage volume for the Vegetated Roof to meet the required goal of managing the 1" rainfall event Design Volume (Dv) for the rooftop area. Different commercially available pre-fabricated Vegetated Roof "panels" may include variations on the growing media depth, porosity and hydraulic conductivity, as well as the geometry and the hydraulic capacity of the underlying drainage layer, and other components. Site designers and planners should consult with Vegetated Roof manufacturers and material suppliers for specific sizing guidelines. As a general sizing rule, **Equation VR-1** can be used to determine the water quality treatment storage volume retained by a Vegetated Roof:

Equation VR-1

$$S_v = (RA \times d \times \eta)/12$$

Where,
Sv = storage volume (cu. ft.)
RA = Vegetated Roof area (sq. ft.)
d = media depth – minimum 4 inches (in.)
η = media porosity (typically 0.25 to 0.3); consult manufacturer's specifications)

The resulting storage volume can then be compared to the target Dv for the entire rooftop area (including all non-vegetated areas) to determine if it meets or exceeds the required volume.

Vegetated Roofs are not designed to capture large storms (2-year, 10-year frequency, etc.). However, the West Virginia Design Compliance Spreadsheet will provide a Curve Number adjustment for individual design storms based on the total storage volume provided as calculated in **Equation VR-1**.

NOTE: Additional credit (i.e. greater than 100% of the Dv for the area of rooftop) is not awarded for providing a deeper growing media section.

VR-4.3. Structural Capacity of the Roof

The physical capacity of the roof to bear structural loads can limit Vegetated Roofs in terms of the additional weight of the fully saturated soil and plants. The designer should consult with a licensed structural engineer as well as the project architect to ensure that the building will be able to support the additional live and dead structural load and determine the maximum depth of the Vegetated Roof system and any needed structural reinforcement.

In most cases, fully-saturated extensive Vegetated Roofs have loads of about 15 to 25 lbs./sq. ft., which is similar to traditional new rooftops (12 to 15 lbs./sq. ft.) that have a waterproofing layer anchored with stone ballast. For a discussion of Vegetated Roof structural design issues, consult **Chapter 9** in Weiler and Scholz-Barth (2009) and ASTM E-2397, *Standard Practice for Determination of Dead Loads and Live Loads Associated with Green Roof Systems*.

VR-4.4. Pre-treatment

Pretreatment is not needed for Vegetated Roofs.

VR-4.5. Conveyance and Overflow

The Vegetated Roof drainage layer (refer to **Section VR-4.1**.) should convey flow from under the growing media directly to an outlet or overflow system such as a traditional rooftop downspout drainage system. The Vegetated Roof drainage layer must be adequate to convey the volume of stormwater equal to the flow capacity of the overflow or downspout system without backing water up onto the rooftop or into the Vegetated Roof media. Roof drains immediately adjacent to the growing media should be boxed and protected by flashing extending at least 3 inches above the growing media to prevent clogging. However, an adequate number of roof drains that are not immediately adjacent to the growing media must be provided so as to allow the roof to drain with minimal ponding above the media.

VR-4.6. Planting Plan

Plant selection, landscaping, and maintenance are critical to the performance and function of Vegetated Roofs. Therefore, a planting plan shall be provided for Vegetated Roofs.

A planting plan must be prepared for a Vegetated Roof by a landscape architect, botanist or other professional experienced with Vegetated Roofs, and it must be reviewed and approved by the local development review authority.

Plant selection for Vegetated Roofs is an integral design consideration, which is governed by local climate and design objectives. The primary ground cover for most Vegetated Roof installations is a hardy, low-growing succulent, such as Sedum, Delosperma, Talinum, Semperivum or Hieracium that is matched to the local climate conditions and can tolerate the difficult growing conditions found on building rooftops (Snodgrass and Snodgrass, 2006).

A list of some common Vegetated Roof plant species that work well in West Virginia can be found in **Table VR-4** below. Designers may also want to directly contact the short list of mid-Atlantic nurseries for Vegetated Roof plant recommendations and availability (**Table VR-5**).

- Plant choices can be much more diverse for deeper intensive Vegetated Roof systems. Herbs, forbs, grasses, shrubs and even trees can be used, but designers should understand they have higher watering, weeding and landscape maintenance requirements.
- The species and layout of the planting plan should reflect the location of building, in terms of its height, exposure to wind, snow loading, heat stress, orientation to the sun, and shading by surrounding buildings. In addition, plants should be selected that are fire resistant and able to withstand heat, cold and high winds.

Table VR-4. Ground Covers appropriate for Vegetated Roofs in West Virginia

Plant	Light	Moisture Requirement	Notes
Delosperma cooperii	Full Sun	Dry	Pink flowers; grows rapidly
Delosperma 'Kelaidis'	Full Sun	Dry	Salmon flowers; grows rapidly
Delosperma nubigenum 'Basutoland'	Full Sun	Moist-Dry	Yellow flowers; very hardy
Sedum album	Full Sun	Dry	White flowers; hardy
Sedum lanceolatum	Full Sun	Dry	Yellow flowers; native to U.S.
Sedum oreganum	Part Shade	Moist	Yellow flowers; native to U.S.
Sedum stoloniferum	Sun	Moist	Pink flowers; drought tolerant
Sedum telephiodes	Sun	Dry	Blue green foliage; native to region
Sedum ternatum	Part Shade-Shade	Dry-Moist	White flowers; grows in shade
Talinum calycinum	Sun	Dry	Pink flowers; self sows

Note: Designers should choose species based on shade tolerance, ability to sow or not, foliage height, and spreading rate. See Snodgrass and Snodgrass (2006) for definitive list of Vegetated Roof plants, including accent plants.

Table VR-5. Vegetated Roof Plant Vendors in the Mid-Atlantic

Riverbend Nursery 1295 Mt. Elbert Road NW Riner, VA 24149 800-638-3362 www.riverbendnursery.com	Emery Knolls Farm 3410 Ady Road Street, Maryland 21154 410-452-5880 www.greenroofplants.com
Carolina Stonecrops, Inc. 159 Bay Shore Drive Nebo, NC 28761 828-659-2851 www.greenroofplants4u.com	North Creek Nurseries, Inc. 388 North Creek Road Landenburg, PA 19350 877-326-7584 www.northcreeknurseries.com
Roofscapes, Inc. 7114 McCallum Street Philadelphia, PA 19119 215-247-8784 www.roofmeadow.com	

- Designers should also match species to the expected rooting depth of the growing media, which can provide enough lateral growth to stabilize the growing media surface. The planting plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on Vegetated Roof plant selection, consult Snodgrass and Snodgrass (2006).
- It is also important to note that most Vegetated Roof plant species will not be native to West Virginia (which contrasts with native plant recommendations for other stormwater practices, such as Bioretention and Stormwater Wetlands).
- Given the limited number of Vegetated Roof plant nurseries in the region, designers should order plants 6 to 12 months prior to the expected planting date. It is also advisable to have plant materials contract-grown (see **Table VR-5** above for a current list of mid-Atlantic Vegetated Roof plant nurseries).
- When appropriate species are selected, most Vegetated Roofs will not require supplemental irrigation, except for temporary irrigation during dry months as the Vegetated Roof is established. The planting window extends from the • Plants can be established using cuttings, plugs, mats, and, more rarely, seeding or containers. Several vendors also sell mats, rolls, or proprietary Vegetated Roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006).
- The goal for Vegetated Roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation that is self-sustaining and requires minimal mowing, trimming and weeding.

The Vegetated Roof design should include non-vegetated walkways (e.g., permeable paver blocks) to allow for easy access to the roof for weeding and making spot repairs.

VR-5. Materials Specifications

Standard specifications for North American Vegetated Roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. The ASTM has recently issued several overarching Vegetated Roof standards, which are described and referenced in **Table VR-6** below.

Designers and reviewers should also fully understand manufacturer specifications for each system component, particularly if they choose to install proprietary "complete" Vegetated Roof systems or modules.

Table VR-6. Extensive Vegetated Roof Material Specifications

Material	Specification
Roof	Structural Capacity should conform to ASTM E-2397-05, Practice for Determination of Live Loads and Dead Loads Associated with Green Roof Systems. In addition, use standard test methods ASTM E2398-05 for Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems, and ASTME 2399-05 for Maximum Media Density for Dead Load Analysis.
Waterproof Membrane	See Chapter 6 of Weiler and Scholz-Barth (2009) for waterproofing options that are designed to convey water horizontally across the roof surface to drains or gutter. This layer may sometimes act as a root barrier.
Root Barrier	Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	Depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive designs. The drainage layer should consist of synthetic or inorganic materials (e.g., gravel, recycled polyethylene, etc.) that are capable of retaining water and providing efficient drainage. Designers should consult the material specifications as outlined in ASTM E2396 and E2398. Roof drains and emergency overflow should be designed in accordance with all applicable building codes.
Filter Fabric	Needled, non-woven, polypropylene geotextile. Density (ASTM D3776) > 16 oz./sq. yd., or approved equivalent. Puncture resistance (ASTM D4833) > 220 lbs., or approved equivalent.
Growth Media	80% lightweight inorganic materials and 20% organic matter (e.g. well-aged compost). Media should have a maximum water retention capacity of around 30%. Media should provide sufficient nutrients and water holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM E2396-05.
Plant Materials	Sedum, herbaceous plants, and perennial grasses that are shallow-rooted, self-sustaining, and tolerant of direct sunlight, drought, wind, and frost. See ASTM E2400-06, Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems.

4.2.9. Vegetated Roofs (VR)

VR-6. Design Adaptations

VR-6.1. Karst Terrain

Vegetated Roofs are an ideal stormwater control measure for karst terrain, although it is advisable to direct downspout discharges at least 15 feet away from the building foundation to minimize the risk of sinkhole formation.

VR-6.2. Cold Climate and Winter Performance

Several design adaptations may be needed for Vegetated Roofs. The most important is to match the plant species to the appropriate plant hardiness zone. In parts of the Chesapeake Bay watershed with colder climates, Vegetated Roofs should be designed so the growing media is not subject to freeze-thaw, and provide greater structural capacity to account for winter snow loads.

VR-6.3. Acid Rain

Much of the mid-Atlantic area experiences acid rain, with rainfall pH ranging from 3.9 to 5.1. Research has shown that Vegetated Roof growing media can neutralize acid rain (Berhage et al. 2007), but it is not clear whether acid rain will impair plant growth or leach minerals from the growing media.

4.2.9. Vegetated Roofs (VR)

VR-7. Construction & Installation

VR-7.1. Vegetated Roof Installation

Given the diversity of extensive Vegetated Roof designs, there is no typical step-by-step construction sequence for proper installation. The following general construction considerations are noted:

- Construct the roof deck with the appropriate slope and material.
- Install the waterproofing method according to manufacturer's specifications.
- Conduct a flood test to ensure the system is water tight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system.
- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric), taking care not to damage the waterproofing. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
- The growing media should be mixed prior to delivery to the site. Media should be spread evenly over the filter fabric surface. The growing media should be covered until planting to prevent weeds from growing. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic. Foot traffic and equipment traffic should be limited over the growing media to reduce compaction.
- The growing media should be moistened prior to planting, and then planted with the ground cover and other plant materials, per the planting plan, or in accordance with ASTM E2400. Plants should be watered immediately after • It generally takes 12 to 18 months to fully establish a Vegetated Roof. An initial fertilization using slow release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support growth. Temporary watering may also be needed during the first summer, if drought conditions persist. Hand weeding is also critical in the first two years (see **Table 10.1** of Weiler and Scholz-Barth, 2009 for a photo guide of common rooftop weeds).
- Most construction contracts should contain a care and replacement warranty that specifies a 75% minimum survival after the first growing season of species planted and a minimum effective vegetative ground cover of 75% for flat roofs and 90% for pitched roofs.

VR-7.2 Construction Inspection

Inspections during construction are needed to ensure that the Vegetated Roof is built in accordance with these specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction and confirm that the contractor's interpretation of the plan is consistent with the intent of the designer and/or manufacturer.

An experienced installer should be retained to construct the Vegetated Roof system. The Vegetated Roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Careful construction supervision is needed during several steps of Vegetated Roof installation, as follows:

- During placement of the waterproofing layer, to ensure that it is properly installed and watertight;
- During placement of the drainage layer and drainage system;
- During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth;
- Upon installation of plants, to ensure they conform to the planting plan;
- Before issuing use and occupancy approvals; and
- At the end of the first or second growing season, to ensure desired surface cover specified in the care and replacement warranty has been achieved.

An example construction phase inspection checklist for Vegetated Roofs can be found in **Appendix A**.

4.2.9. Vegetated Roofs (VR)

VR-8. Maintenance Criteria

VR-8.1. Maintenance Inspections and Operations

A Vegetated Roof should be inspected twice a year during the growing season to assess vegetative cover, and to look for leaks, drainage problems and any rooftop structural concerns (see **Table VR-7** below). In addition, the Vegetated Roof should be hand-weeded to remove invasive or volunteer plants, and plants/media should be added to repair bare areas according to ASTM E2400 (ASTM, 2006).

If a roof leak is suspected, it is advisable to perform an electric leak survey (i.e., Electrical Field Vector Mapping) to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides should be avoided, since their presence could hasten degradation of the waterproof membrane. Also, power-washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the Vegetated Roof plant communities.

Part II, Section C.b.5.ii(C) of the MS4 General Permit requires a maintenance agreement and plan between the property owner or operator and the local program authority (for municipal separate storm sewer systems). This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

Vegetated Roofs must be covered by a drainage easement to allow inspection and maintenance.

An example maintenance inspection checklist for Vegetated Roofs can be found in **Appendix A**.

Table VR-7. Typical Maintenance Activities Associated with Vegetated Roofs

Activity	Schedule
• Water to promote plant growth and survival. • Inspect the roof and replace any dead or dying vegetation.	As Needed (following construction)
• Inspect the waterproof membrane for leaking or cracks. • Annual fertilization (first five years). • Weeding to remove invasive plants (no digging or using pointed tools). • Inspect roof drains, scuppers and gutters to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris. • Inspect the roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed.	Semi-Annually

REFERENCES

ASTM International. 2006. Standard Guide for Selection, Installation and Maintenance of Plants for Green Roof Systems. Standard E2400-06. ASTM, International. West Conshohocken, PA. available online: http:// www.astm.org/Standards/ E2400.htm.

Berhage, R., A. Jarrett, D. Beattie and others. 2007. Quantifying evaporation and transpiration water losses from green roofs and green roof media capacity for neutralizing acid rain. Final Report. National Decentralized Water Resource Capacity Development Project Research Project. Pennsylvania State University.

Clark, S., B. Long, C. Siu, J. Spicher and K. Steele. 2008. "Early-life runoff quality: green versus traditional roofs." Low Impact Development 2008. Seattle, WA. American Society of Civil Engineers.

Dunnett, N. and N. Kingsbury. 2004. Planting Green Roofs and Living Walls. Timber Press. Portland, Oregon.

Hirschman, D., Collins, K., and T. Schueler. 2008. Technical Memorandum: The Runoff Reduction Method. Center for Watershed Protection and Chesapeake Stormwater Network. Ellicott City, MD.

Northern Virginia Regional Commission (NVRC). 2007. Low Impact Development Manual. "Vegetated Roofs." Fairfax, VA.

Snodgrass, E. and L. Snodgrass. 2006. Green Roof Plants: a resource and planting guide. Timber Press. Portland, OR.

Weiler, S. and K. Scholz-Barth 2009. Green Roof Systems: A Guide to the Planning, Design, and Construction of Landscapes over Structure. Wiley Press. New York, NY.

4.2.10. Filtration Practice (FP)

FP-1. Introduction

Filtration practices are practices that capture and temporarily store a portion of the Design Volume in a pretreatment sedimentation chamber or a surface ponding area and then pass it through a filter bed of sand or other media. Filtered runoff is then collected and returned to the conveyance system.

Filtration practices can be used to:

- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs; See **Table FP-2**).
- Provide pretreatment for other practices that require extensive pretreatment to be effective, such as Infiltration.
- Retrofit existing developed areas, especially highly impervious areas, by reducing pollutant loads.

Filtration practices can be applied as underground vault systems or as a surface sand filter.

A surface Filtration practice is differentiated from a Bioretention or Water Quality Swale practice by the use of 100% sand as a filter media and the lack of a vegetated layer. Sand is generally considered a high rate filter since the runoff will pass through the media extremely fast (filtration rate of 16 ft/day and up) and therefore Filtration practices provide no runoff reduction credit.

Design variants include:

- Surface Sand Filter
- Three-Chamber Underground Sand Filter
- Perimeter Sand Filter

Figure FP-1 further illustrates typical applications of Filtration practices, and **Figure FP-2** is a typical schematic. **Figures FP-3 through FP-5** are schematics of typical Filtration practices. **Tables FP-1 and FP-2** describe two levels of Filtration design and associated pollutant removal performance rates. **Table FP-3** is a design checklist to help guide the design process for Filtration practices.

FP-1.1. Planning This Practice

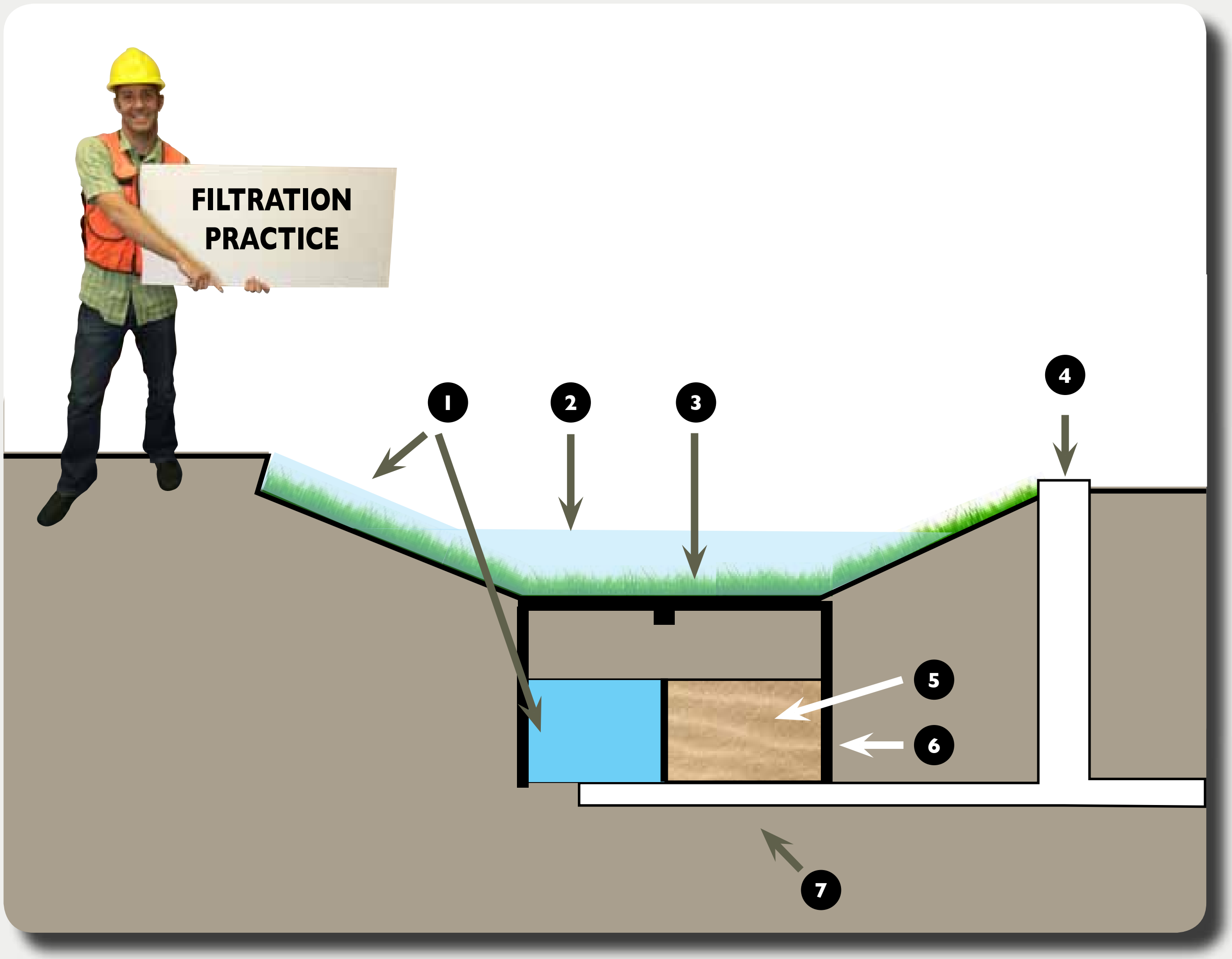
Figure FP-1. Typical Applications of Filtration Practices

Surface Sand Filter

Underground Sand Filter
Photo Courtesy of Albemarle County, VA

Perimeter Sand Filter

Figure FP-2. Typical Schematic for Filtration Practice



1. Pretreatment (typical grass filter strip and/or sedimentation chamber) – **Section FP-4.3**
2. Filter ponding depth – **Section FP-4.5**
3. Surface cover (surface sand filter only) – **Section FP-4.9**
4. Conveyance and overflow for larger flows – **Section FP-4.4**
5. Filter Media – **Sections FP-4.1 & FP-4.8**
6. Geotextile fabric – **Section FP-4.11**
7. Underdrain – **Section FP-4.10**

FP-1.2. Filtration Design Options & Performance

Table FP-1 describes the Level 1 and Level 2 design options and performance credits for Filtration practices. Note that Filtration practices do not meet the MS4 General Permit criteria to "keep and manage on-site the first one-inch of rainfall" and thus do not have an associated runoff reduction performance credit and do not contribute to reducing the overall Target Treatment Volume. Filtration practices can, however, be used in conjunction with Infiltration practices (or other runoff reduction practices) as a "high-end" pretreatment system to ensure the longevity of the Infiltration facility. **Table FP-2** summarizes pollutant removal performance values for Level 1 and Level 2 designs. Note that Filtration practices are very effective at removing pollutant loads for the purpose of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans.

Table FP-1. Filtration Practices Design Levels: Descriptions & Performance

Design Level	Description	Applications	Performance Achieved Towards Reducing 1" of Rainfall
Level 1	One cell design Sand media Contributing drainage area (CDA) contains pervious area	Sites with vertical constraints such as high bedrock or water table OR confirmed karst, stormwater hotspot, or other applications that require an impermeable liner.	0% volume reduction for the Design Volume of the practice[1]
Level 2	Two cell design Sand media with an organic layer CDA is nearly 100% impervious	Generally most sites that have marginal infiltration rates -- Hydrologic Soil Group (HSG) C, and do not require an impermeable liner.	0% volume reduction for the Design Volume of the practice[1]

[1] *May be increased if the 2nd cell is utilized for Infiltration in accordance with **Specification 4.2.6, Infiltration or Specification 4.2.3, Bioretention**. The runoff reduction credit should be proportional to the fraction of the Design Volume designed to be infiltrated.*

Table FP-2. Total Pollutant Load Reduction Performance Values for Level 1 and 2 Design

Design Level	Total Suspended Solids (TSS)[1]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN) [1]
Level 1	TSS = 60%	TP = 60% TN = 30%
Level 2	TSS = 85%	TP = 65% TN = 45%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008). Filtration does not receive any runoff reduction credit; so Total Pollutant Load Reduction will improve significantly if Infiltration is incorporated into Level 1 or Level 2 Filtration design.

FP-1.3. Filtration Design Checklist

Table FP-3. Filtration Design Checklist

CHECKLIST

This checklist will help the designer through the necessary design steps for Filtration practices.

- ☐ Ascertain the regulatory context of using a Filtering Practice, how the Filtering Practice will be used in conjunction with runoff reduction practices, and how the 1" performance standard can be met on the site or partially waived to allow a water quality treatment practice in conjunction with or in lieu of runoff reduction practices. This will likely require consultation with the local program and West Virginia Department of Environmental Protection (WVDEP).
- ☐ Check feasibility for site – (typically includes available depth to bedrock for an underground system) **Section FP-3**
- ☐ Determine whether a Level 1 or Level 2 design will work for the site. Use Level 2 design unless site constraints necessitate Level 1 design – **Table FP-1**
- ☐ Complete Design Compliance Spreadsheet to determine if the limited credit of Filtration (pollutant removal only) is adequate; or if additional practices are needed for overall site compliance – Design Compliance **Spreadsheet & Chapter 3 of Manual**
- ☐ Check sizing guidance and make sure there is an adequate room for Filtration practice footprint on the site – **Section FP-4.2**
- ☐ Check design adaptation appropriate to the site – **Section FP-6**
- ☐ Design Filtration system in accordance with design criteria and typical details – **Sections FP-2 & FP-4**
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence notes.

4.2.10. Filtration Practice (FP)

FP-2. Typical Details

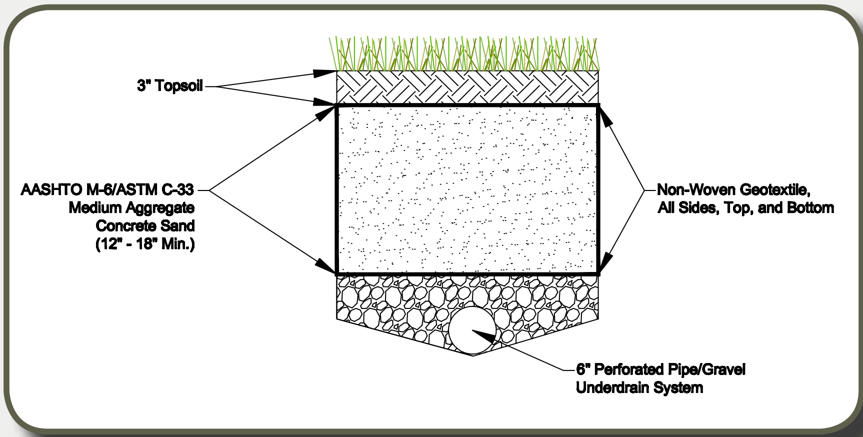


Figure FP-3. Schematic Profile for Typical Surface Sand Filter

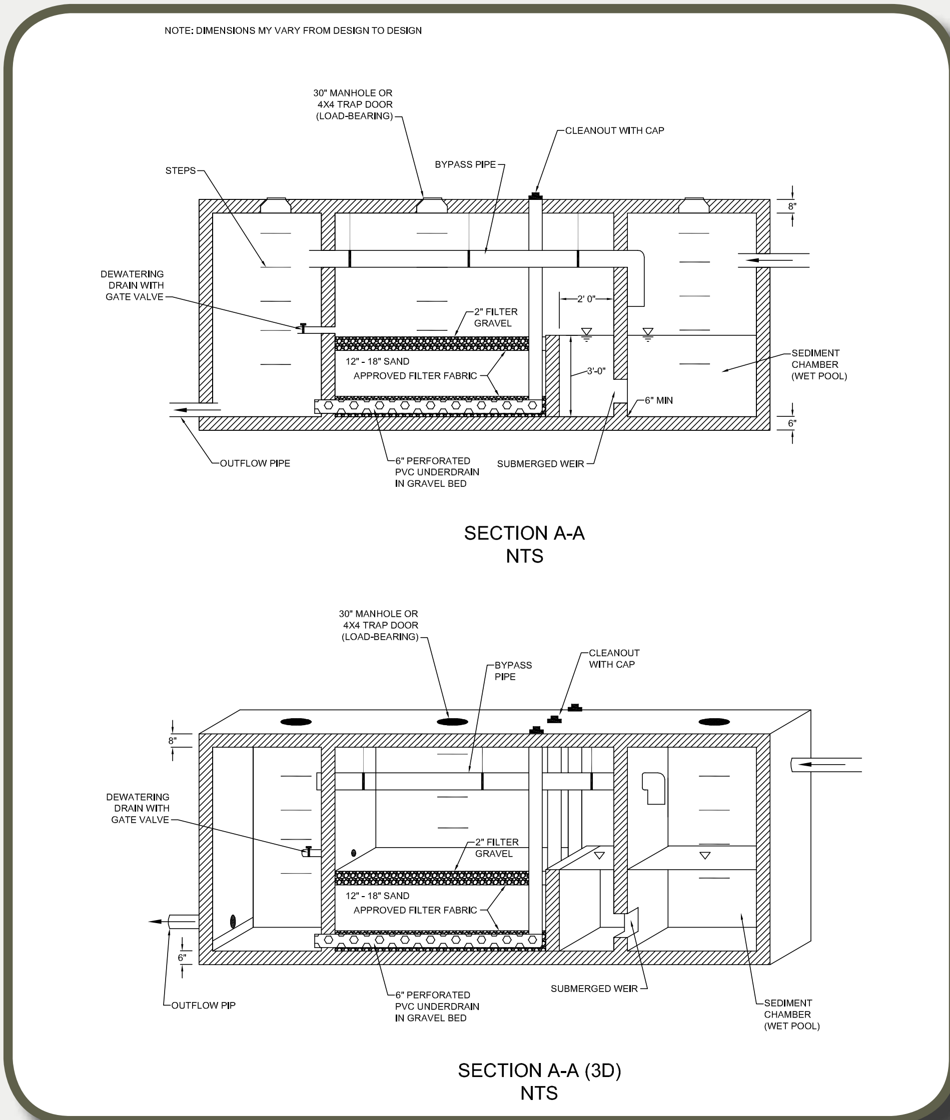


Figure FP-4. Example of Three-Chamber Underground Sand Filter

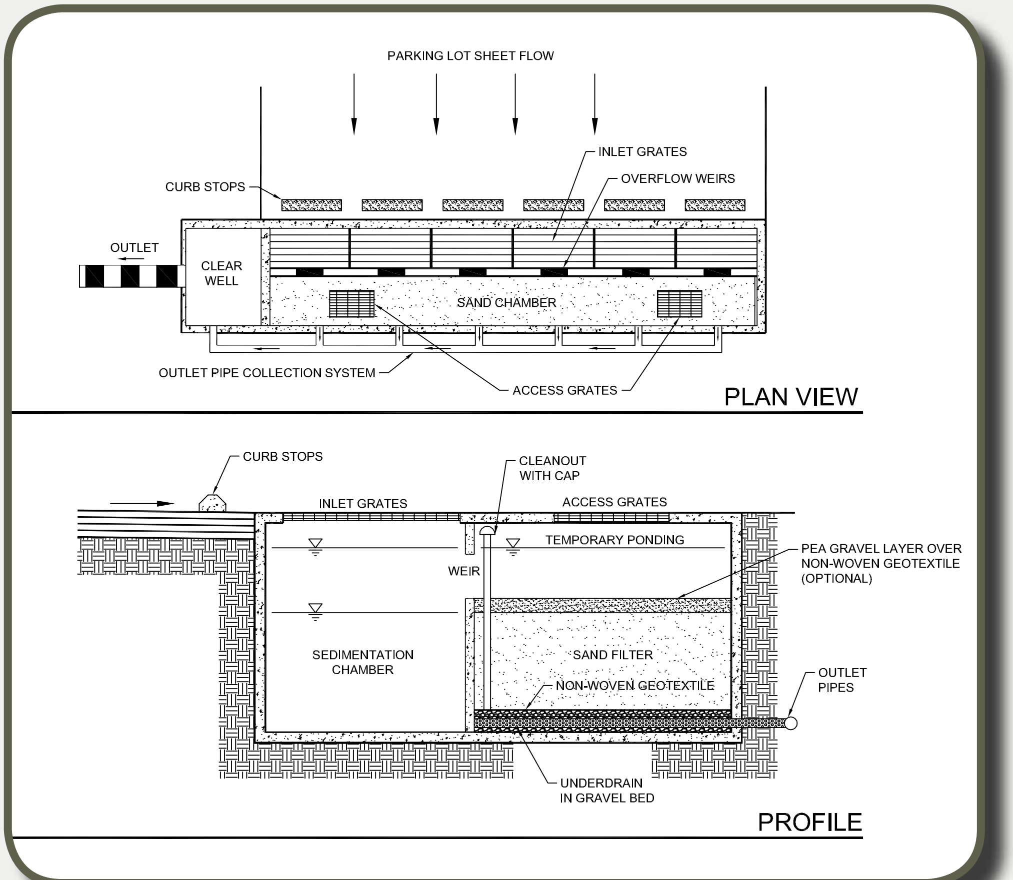


Figure FP-5. Example of Perimeter Sand Filter

4.2.10. Filtration Practice (FP)

FP-3. Feasibility Criteria and Design Considerations

Filtration practices can be applied to most types of urban land. They are not always cost-effective, given their high unit cost and small area served, but there are situations where they may clearly be the best option for stormwater treatment, such as stormwater hotspots, high traffic parking lots with high pollutant loading, and ultra-urban areas, etc. Key constraints with Filtration practices include the following:

Available Space. The amount of space required for a Filtration practice depends on the design variant selected. Surface sand filters typically consume about 1% to 3% of the CDA, while perimeter sand filters typically consume less than 1%. Underground sand filters generally consume no surface area except their manholes. Perimeter sand filters, while located below grade, have a parallel grate and frame and cover (as depicted in **Figure FP-1**.)

Site Topography. Surface filters shall not be located on slopes greater than 6%. Underground sand filters can be located on steep slopes as long as the manhole chimneys are designed to provide access at grade (adequate manhole diameter for the corresponding height of chimney).

Available Hydraulic Head. The principal design constraint for Filtration practices is available hydraulic head, which is defined as the vertical distance between the ponding surface elevation of the pretreatment sedimentation chamber of the filter and the invert elevation of the storm drain system that receives its discharge. The head required for Filtration practices can range from 2 to 10 feet, depending on the design variant, making it difficult to employ filters in extremely flat terrain. The only exception is the perimeter sand filter, which can be applied at sites with as little as 2 feet of head.

Depth to Water Table and Bedrock. Filtering Practices that do not incorporate Infiltration as part of the system are not constrained by bedrock or water table other than the constructability of the practice. Underground systems may require deep excavation that intersects with bedrock or water table, so these factors must be considered in terms of constructability.

Soils. Soil conditions do not constrain the use of filters. At least one soil boring must be taken at a low point within the footprint of the proposed Filtration practice to establish the water table and bedrock elevations to evaluate constructability. A geotechnical investigation is required for all underground best management practices (BMPs), including underground sand filters to verify the load bearing capacity of the existing soils and any special footing requirements.

Contributing Drainage Area. Filtration practices are best applied on small sites where the CDA area is as close to 100% impervious as possible in order to reduce the risk of clogging due to landscape and pervious area sediment erosion. A maximum CDA of 2.5 acres is recommended for surface sand filters, and a maximum CDA of 1 to 2 acres is recommended for underground sand filters. Filtration practices have been used on larger drainage areas in the past, but greater clogging problems have typically resulted.

The perimeter sand filter is only applicable for impervious areas less than 10,000 ft2 (1/4 acre). However, independent perimeter sand filter cells can be employed to treat a combined larger area.

Hotspot Land Uses. As noted above, Filtration practices are particularly well suited to treat runoff from stormwater hotspots and smaller parking lots. Other applications include redevelopment of commercial sites or when existing parking lots are renovated or expanded. Filtration practices can work on most commercial, industrial, institutional or municipal sites and can be located underground if surface area is not available.

For a list of potential stormwater hotspots, please consult **Chapter 5** of the Manual.

Floodplains. Filtration practices should be constructed outside the limits of the mapped 100-year floodplain, unless a waiver is obtained from the local authority.

Proximity to Utilities. All utilities shall have a minimum 5 foot horizontal clearance from the Filtration practices.

Facility Access. All Filtration practices shall be located in areas where they are accessible for inspection and for maintenance. Maintenance to underground systems is typically by vacuum truck, so adequate access must be planned during initial site design.

Community Factors. Maintenance requirements for underground sand filters can be very technical (and often require confined space credentials in order to perform basic inspections) such that underground sand filter systems are not recommended for single family residential developments (and there are numerous other BMP options better suited for residential areas). Either underground or surface sand filters may be considered for high density residential areas, but should be maintained by a contractor through a community association.

Underground Injection Permits. Filtration practices areas are not subject to permits under the Underground Injection Control (UIC) Program (U.S. EPA, 2008) unless there is an additional component that includes Infiltration in close proximity to sensitive groundwater areas (e.g., aquifers overlain with thin, porous soils), designs with a subsurface fluid distribution system (e.g., underdrains that do not discharge to the surface or the storm drain system), and/or designs that are deeper than their widest surface dimension. The designer should confer with WVDEP or the local plan approving authority about the possible applicability of a UIC permit when these conditions are present.

4.2.10. Filtration Practice (FP)

FP-4. Design Criteria

FP-4.1. Types of Filters

There are several design variations of the basic Filtration practice that enable them to be used at challenging sites or to improve pollutant removal rates. Filtration practices are especially useful at hotspots or high traffic/high pollutant loading sites where a robust pre-treatment practice is essential for the long term effectiveness of a downstream runoff reduction practice such as Infiltration or Bioretention.

The choice of which filter design to apply depends on available space and hydraulic head and the level of pollutant removal desired. In ultra-urban situations where surface space is at a premium, underground sand filters are often the only design that can be used. Surface and perimeter sand filters are often a more economical choice when adequate surface area is available. The most common design variants include the following:

- **Surface Sand Filter.** The surface sand filter is designed with both the filter bed and sediment chamber located at ground level. The most common filter media is sand; however, a peat/sand mixture may be used to increase the removal efficiency of the system. In most cases, the filter chambers are created using pre-cast or cast-in-place concrete. Surface sand filters are normally designed to be off-line facilities, so that only the desired water quality or runoff reduction volume is directed to the filter for treatment. However, in some cases they can be installed on the bottom of a Dry Extended Detention Pond.
- **Underground Sand Filter.** The underground sand filter consists of an underground concrete vault divided into chambers to accommodate the pretreatment, filter, and outlet chambers. The underground sand filter is often designed with a flow splitter or overflow device that bypasses runoff from larger stormwater events around the filter. Underground sand filters are expensive to construct, but they consume very little space and are well suited to ultra-urban areas.

The most common configuration of an underground sand filter is the gravity flow three-chambered system that can either be a pre-cast or cast-in-place concrete vault with access manholes to each chamber.

- The first chamber acts as a pretreatment facility that contains a standing pool of water and is configured with a submerged orifice to remove any floating organic material such as oil, grease, and tree leaves. The chamber also serves as a sedimentation chamber to allow coarse sediments to settle to the bottom rather than clog the filter media surface. This chamber should therefore be designed to minimize the energy of incoming stormwater to avoid re-suspension of settled material. **Figure FP-3** illustrates a common configuration of the pretreatment design as having two chambers.
- The second chamber is the filter chamber and contains the 12' to 18' deep filter bed underlain by a drain system consisting of parallel perforated PVC pipes in a gravel bed. A dewatering valve should be installed at the top of the filter layer to release the ponded water in cases of media failure (clogging) or an emergency.

  The configuration of the filter bed material has been modified over the years to theoretically improve the filter media longevity and minimize maintenance costs:
  - One option is the placement of a shallow layer of pea gravel directly on the sand. The gravel serves to break up the growth of algae that often blinds (seals) the sand surface after repeated wet/dry cycles.
  - Expanding on the pea gravel option to assist in maintenance, some applications include a non-woven geotextile fabric between the sand and the gravel to assist in periodic removal of the gravel.

Consider the Difficulty of Maintenance Tasks

While the pea gravel and geotextile options discussed above were intended to facilitate maintenance by prolonging the longevity and thereby minimizing the frequency of maintenance, they both serve to complicate maintenance of the system. The removal of gravel is difficult through the access manholes (volume and weight). Similarly, the removal of a large sheet of filter fabric that is loaded with saturated sediment and gravel is also very difficult.

  - An alternate approach is to enhance the pretreatment chamber by incorporating baffles and energy dissipaters, and increase the media depth to 18" or 24". This will serve to minimize the sediment load to the filter media. In addition, the deeper media depth will facilitate maintenance by allowing for the periodic scraping and removal of the top 1" of sand media, leaving an adequate media depth for continued operation (the depth of clogging of the sand media is often limited to the first inch)

- The third chamber is the discharge chamber. It receives the discharge from the underdrain system as well as the overflow from the first chamber through a bypass pipe when the storage volume is exceeded.

- **Perimeter Sand Filter.** The perimeter sand filter also includes the basic design elements of a sediment chamber and a filter bed. The perimeter sand filter typically consists of two parallel trenches connected by a series of overflow weir notches at the top of the partitioning wall which allows water to enter the second trench as sheet flow; or where heavy hydrocarbon loading is expected, a series of submerged orifices with energy dissipaters on the outlets. The first trench is a pretreatment chamber removing heavy sediment particles and debris, or floatable oils. The second trench consists of the sand filter layer. A subsurface drainage pipe is at the bottom of the second chamber to convey the filtered water to a receiving system.

In this design, flow enters the system through grates, usually at the edge of a parking lot. The perimeter sand filter is usually designed as an on-line practice (i.e., all flows enter the system), but larger events bypass treatment by entering an overflow chamber. One major advantage of the perimeter sand filter design is that it requires little hydraulic head and is therefore a good option for sites with low topographic relief.

- **Proprietary Filters.** Proprietary filters use various filter media and geometric configurations to achieve filtration and provide manageable maintenance processes and access within a packaged structure. In some cases, these systems can provide excellent targeting of specific pollutants. However, designers must verify that the particular product has been reviewed for performance, sizing, and longevity and has been approved as a viable practice by WVDEP.

FP-4.2. Filtration Practice Sizing for Water Quality & Volume Reduction

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a BMP plan:

Target Treatment Volume (Tv) = Volume associated with managing 1" of rainfall based on the size and land cover of the CDA, as determined by the Design Compliance Spreadsheet. Any given BMP may treat the full Tv, or only part of it if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on storage in the practice, as prescribed in the BMP specification. Note that, while Filtration practices can be designed to store temporarily a particular Dv, they do not meet the MS4 General Permit criteria to "keep and manage on-site the first one-inch of rainfall" and thus do not have an associated runoff reduction credit and do not contribute to reducing the overall Tv. However, Filtration practices do achieve pollutant removal rates as outlined in Table FP-2. Designers should check with the local plan approval authority on use and approval of Filtration practices as part of an overall BMP plan.

See **Chapter 3** for more information on the runoff reduction design methodology.

For the purposes of this sizing section, the sizing relates to the Dv of the Filtration practice being designed.

Filtration devices are sized to accommodate the Dv. The filter components that are sized according to the Dv are the pre-treatment or sedimentation chamber volume, the surface area of the filter, and the volume of ponding storage above the filter. For a given design volume, **Equation FP-1**, Darcy's Law, is used to determine the required filter surface area:

Equation FP-1. Darcy's Law
Minimum Filter Surface Area for Filtration Practices

$$SA_{filter} = \frac{(Dv)(d_f)}{[(k)(h_{avg} + d_f)(t_f)]}$$

Where:

SA_{filter}	=	area of the filter surface (ft2)
Dv	=	Design Volume (ft3)
df	=	filter media depth (thickness, ft) = minimum 1 ft above underdrains
k	=	Coefficient of permeability (partially clogged sand) = 3.5 ft/day
hf	=	Average height of water above filter surface bed (ft) = maximum 5 ft
tf	=	Design drawdown time (days) = 40 hours = 1.67 days

The coefficient of permeability (ft./day) is intended to reflect the worst case situation (i.e., the condition of the sand media at the point in its operational life where it is in need of replacement or maintenance). Filtering practices are therefore sized to properly function within the desired constraints up to the end of the media's operational life.

The entire filter treatment system (including the pretreatment/sedimentation and any additional storage upstream of the filter system) shall temporarily hold at least 75% of the design storm volume prior to filtration (**Equation FP-2**). This reduced volume takes into account the varying filtration rate of the water through the media, as a function of a gradually declining hydraulic head.

Equation FP-2. Required Volume of Storage for Filtration Practices

$$V_{ponding} = 0.75(Dv)$$

Where:

$V_{ponding}$	=	storage volume required prior to filtration (ft^3)
Dv	=	Design Volume

Pre-Treatment is Essential

Adequate pre-treatment is needed to prevent premature filter clogging and ensure filter longevity. Incorporating baffles, submerged orifices, and other techniques into the pre-treatment/sedimentation chamber will improve performance longevity and therefore reduce maintenance costs.

An effective method of increasing the functional longevity of the filter is to limit the drainage area to impervious cover only. This helps to minimize the sources of sediment and organic material that combine to clog the surface of filtering practices.

Dry or wet pretreatment shall be provided prior to the filter media of surface sand filters. **Figure FP-6** shows various pre-treatment options for filters, and **Figure FP-7** is a detail for pre-treatment as the pavement edge.

Wet pretreatment shall be provided for underground and perimeter sand filters.

Pre-treatment devices are subject to the following criteria:

- Surface sand filters may use alternative pre-treatment measures, such as a grass filter strip, forebay, gravel diaphragm, check dam, level spreader, or combination.
    - o The grass filter strip must be a minimum length of 15 feet and have a slope of 3% or less.
    - o The check dam may be wooden or concrete and must be installed so that it extends only 2 inches above the filter strip and has lateral slots to allow runoff to be evenly distributed across the filter surface.
    - o Alternative pre-treatment measures should contain a non-erosive flow path that distributes the flow evenly over the filter surface.
    - o If a forebay is used it should be designed to accommodate at least 25% of the total design storm volume (both the wet pool and temporary ponding inclusive).
- Sedimentation chambers for underground sand filters must be wet and sized to accommodate at least 25% of the total design storm volume (both the wet pool and temporary ponding inclusive).
- Sediment chambers for underground sand filters should be designed as level spreaders such that inflows to the filter bed have near zero velocity and spread runoff evenly across the bed.
- If proprietary devices are used for pre-treatment for underground sand filters, designers must confirm through WVDEP that the practice has been approved with the capability to effectively trap and retain particles down to 20 microns in size for the design flow rate (up to the bypass flow rate design).

FP-4.3. Pretreatment

Figure FP-6. Examples of Pre-Treatment Applicable to Filtration Practices

Grass filter strips are generally perpendicular to incoming sheet flow and extend from the edge of pavement (with a slight drop of 2 to 3 inches at the pavement edge) to the edge of the Filtration basin. The grass filter strip must be a minimum width of 15 feet and have a slope of 3% or less.

This **Dry Pre-Treatment Cell** or forebay is located at concentrated inflow points such as pipes or curb cuts leading to the Filtration practice, and consists of an energy dissipater sized for the expected rates of discharge. It has a Design Volume equivalent to at least 25% of the total storage volume (inclusive) with a recommended 2:1 length-to-width ratio. The cell may be formed by a wooden or stone check dam or an earthen or rock berm.

A **Grass Swale** can serve as pre-treatment to a Filtration practice.

An approved **Proprietary Device** with demonstrated capability of reducing sediment and hydrocarbons may be used to provide pre-treatment. Refer to **Chapter 3.2.4** for information on the approval process for such devices.

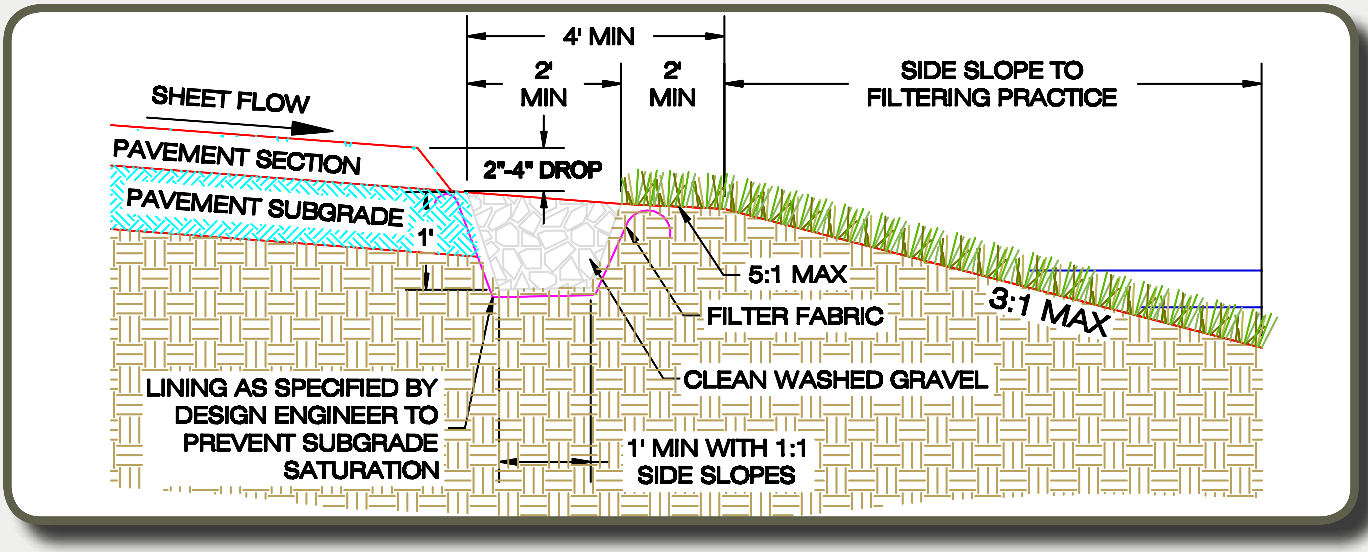


Figure FP-7. Typical Detail for Pre-Treatment at Pavement Edge – A 2 to 4 inch drop from the pavement to the top of stone helps to prevent clogging.

FP-4.4. Conveyance and Overflow

Most Filtration practices are designed as off-line systems so that all flows enter the filter storage chamber until the chamber reaches capacity, at which point larger flows are then diverted or bypassed around the filter to an outlet chamber and are not treated. Runoff from larger storm events should be bypassed using an overflow structure or a flow splitter. Claytor and Schueler (1996) and ARC (2001) provide design guidance for flow splitters for Filtration practices.

Some underground sand filters will be designed and constructed as on-line BMPs. In these cases, designers must indicate how the device will safely pass larger storm events (e.g., the 10-year event) to a stabilized water course without re-suspending or flushing previously trapped material.

All Filtration practices should be designed to drain or dewater within 40 hours after a storm event to reduce the potential for nuisance conditions.

FP-4.5. Design Geometry

Filtration practices are gravity flow systems that may require anywhere from 2 to 10 feet of elevation from inflow to outflow, depending on the design variant and the sizing of the individual filter components or chambers; therefore, sufficient vertical clearance between the inverts of the inflow and outflow pipes is required.

The sizing of the individual system components includes the ponding depth and the filter media depth. Since Darcy's Law calculates the surface area of the filter using media permeability (K-factor, independent of ponding depth), the ponding depth (to derive filtration rate), and the media depth, it is important to establish the minimum and maximum for these variables to maintain the appropriate relationship between the Design Volume and the filter surface area.

- **Ponding Depth.** The recommended maximum ponding depth on Filtration practices is 5 feet. This is to establish a maximum overall depth so that maintenance can be achieved in a practical manner. A maximum depth will also prevent the inappropriate downsizing of the filter media surface area, as a minimum surface area is needed to achieve the intended level of filtration.
- **Media Depth.** The minimum recommended media depth or thickness is 12 inches. However, setting the depth at 18 to 24 inches will facilitate periodic scraping and removal of the top 1 inch of media (or as needed) when the surface of the filter is occluded. Establishing the deeper media will allow for multiple maintenance events without

having to replace the sand media. Alternatively, a very shallow media depth will result in a larger required filter media surface area. So even though a shallower media depth may be effective in filtering runoff, the minimum design depth must be 12 inches, and preferably 18 inches to support a longer maintenance cycle.

Limit the Design Geometry of the Ponding and Media Depth

The design dimensions of Filtration system components must be limited to minimum or maximum values in order to ensure the proper ratio of Design Volume to media surface area when using Darcy's Law to size the practice.

FP-4.6. Detention Time

All Filtration practices should be designed to drain the Design Volume from the filter chamber within 40 hours after each rainfall event.

FP-4.7. Structural Requirements

If a filter will be located underground or experience traffic loads, a licensed structural engineer should certify the structural integrity of the design.

FP-4.8. Filter Media

- **Type of Filter Media.** The normal filter media consists of clean, washed AASHTO M-6/ASTM C-33 medium aggregate concrete sand with individual grains between 0.02 and 0.04 inches in diameter.
- **Depth of Filter Media.** The depth of the filter media plays a role in how quickly stormwater moves through the filter bed and how well it removes pollutants. The recommended filter bed depth is 18 inches. An absolute minimum filter bed depth of 12" above underdrains is required, although designers should note that specifying the minimum depth of 12" will incur a more intensive maintenance schedule and possibly result in greater annual maintenance cost.

FP-4.9. Surface Cover

The surface cover for surface sand filters should consist of a 3-inch layer of topsoil on top of a non-woven filter fabric laid above the sand layer (**Figure FP-8**).

If an underground sand filter is observed to be clogging due to bio-fouling or surface blinding, a surface pea gravel layer on top of a coarse non-woven fabric can be laid over the sand layer after a maintenance event. The pea-gravel helps to prevent bio-fouling or blinding of the sand surface. The fabric serves to facilitate removing the gravel during maintenance operations. Bio-fouling is especially prevalent on sites where large air-conditioning condensers discharge cool water to the drainage system and into the underground sand filter on a continuous basis.

Figure FP-8. Gravel forebay and top soil and turf cover over the sand media (Source: Chesapeake Stormwater Network)

FP-4.10. Underdrains

Filtration practices include an underdrain system that meets the criteria provided in **Table FP-4** below. The underdrain should be covered by a minimum 6-inch gravel layer consisting of clean, washed #57 stone.

FP-4.11. Geotextile Fabric

A non-woven geotextile should be placed beneath the filter media and above the underdrain gravel layer. The geotextile should meet the criteria provided in **Table FP-4** below.

FP-4.12. Impermeable Liner

Surface sand filters can be designed with an impermeable liner below the underdrain system in karst areas or areas constructed in fill materials. Refer to **Table FP-4** below for specifications.

FP-4.13. Signage

Informational and/or educational signage may be appropriate for surface sand filters. The location of manhole access points should be documented for underground sand filters.

FP-4.14. Planting Criteria

Surface sand filters can have a grass cover to aid in the pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought.

4.2.10. Filtration Practice (FP)

FP-5. Materials Specifications

The basic material specifications for Filtration practices that utilize sand as a filter media are outlined in **Table FP-4**.

Table FP-4. Filtration Practice Material Specifications

Material	Specification
Surface Cover	***Surface sand filters:*** 3-inch layer of topsoil on top of a non-woven geotextile above the sand layer. ***Underground sand filters:*** Optional - Pea gravel layer on top of a coarse non-woven geotextile laid over the sand layer.
Sand	Clean AASHTO M-6/ASTM C-33 medium aggregate concrete sand with a particle size range of 0.02 to 0.04 inch in diameter.
Underdrain	The underdrain should consist of High Density Polyethylene smooth or corrugated flexible-wall pipe. Pipes must comply with ASHTO M252 and ASTM F405. Underdrains meeting ASTM F758 should be perforated with slots that have a maximum width of 3/8 inch and provide a minimum inlet area of 1.76 square inches per linear foot of pipe. Underdrains meeting ASTM F949 should be perforated with slots with a maximum width of 1/8 inch that provide a minimum inlet area of 1.5 square inches per linear foot of pipe. Underdrain pipe supplied with precision-machined slots provides greater intake capacity and superior clog-resistant drainage of fluids, as compared to standard round-hole perforated pipe. Slotted underdrain reduces entrance velocity into the pipe, thereby reducing the possibility that solids will be carried into the system. Slot rows can generally be positioned symmetrically or asymmetrically around the pipe circumference, depending upon the application.
Non-woven Geotextile	Use needled, non-woven, polypropylene geotextile meeting the following specifications: Grab Tensile Strength (ASTM D4632) ≥ 120 lbs Mullen Burst Strength (ASTM D3786) ≥ 225 lbs/sq. in. Flow Rate (ASTM D4491) ≥125 gpm/sq. ft. Apparent Opening Size (ASTM D4751) = US #70 or #80 sieve NOTE: Heat-set or heat-calendared fabrics are not recommended.
Underdrain Stone	Use #57 stone or the ASTM equivalent (1 inch maximum).
Impermeable Liner	Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile.

FP-6. Design Adaptations

FP-6.1. Karst Terrain

Karst regions are found in much of the Ridge and Valley and Panhandle. Karst complicates both land development and stormwater design. Filtration practices are a good option in karst areas, since they are not connected to groundwater and therefore minimize the risk of sinkhole formation and groundwater contamination. Construction inspection should certify that the filters are indeed water tight and that excavation will not extend into a karst layer.

FP-6.2. Steep Slopes

The gradient of slopes contributing runoff to surface sand filters can be increased to 15% in areas of steep terrain, as long as a two cell, terraced design is used to dissipate erosive energy prior to filtering. The drop in elevation between cells should be limited to 1 foot and the slope should be armored with river stone or a suitable equivalent.

Underground sand filter performance is generally not limited by the steepness of the CDA other than to recognize the potential for pervious areas to contribute greater loads of sediment.

FP-6.3. Cold Climate and Winter Performance

Surface or perimeter sand filters may not always be effective during the winter months. The main problem is ice that forms over and within the filter bed. Ice formation may briefly cause nuisance flooding if the filter bed is still frozen when spring melt occurs. To avoid these problems, filters should be inspected before the onset of winter (prior to the first freeze) to dewater wet cells and scarify the filter surface. Other measures to improve winter performance include the following:

- Place a weir between the pre-treatment chamber and filter bed to reduce ice formation; the weir is a more effective substitute than a traditional standpipe orifice.
- Extend the filter bed below the frost line to prevent freezing within the filter bed.
- Oversize the underdrain to encourage more rapid drainage and to minimize freezing of the filter bed.
- Expand the sediment chamber to account for road sand. Pre-treatment chambers should be sized to accommodate up to 40% of the Design Volume.

FP-6.4. Stormwater Retrofitting

Filtration practices are a versatile retrofit option that offer moderate pollutant removal performance. They are especially attractive for on-site retrofits where space is limited, because they consume very little surface land and have few site restrictions.

For more information on retrofitting, see the Center for Watershed Protection's manual, Urban Stormwater Retrofit Practices (Schueler et al., 2007).

FP-7. Construction & Installation

FP-7.1. Erosion and Sediment Controls

No runoff shall be allowed to enter the Filtration practice prior to completion of all construction activities, including revegetation and final site stabilization. Construction runoff shall be treated in separate sedimentation basins and routed to bypass the Filtration system. Should construction runoff enter the system prior to final site stabilization, all contaminated materials must be removed and replaced with new clean filter materials before a regulatory inspector approves its completion. The approved erosion and sediment control plans shall include specific measures to provide for the protection of the Filtration practice before the final stabilization of the site.

Drainage Areas Should Be Stabilized Before Installation of Underdrains & Sand Media

The #1 source of failure for sand filters is installation too early during the construction process and/or lack of erosion control measures during installation. Construction sediment will readily clog the sand media. Drainage areas to sand filter areas should be stabilized with vegetation prior to installation of these materials.

FP-7.2. Filter Installation

The following is the typical construction sequence to properly install a structural sand filter. This sequence can be modified to reflect different filter designs, site conditions, and the size, complexity and configuration of the proposed Filtration application.

Step 1. Filtration practices should only be constructed after the CDA to the facility is completely stabilized, so sediment from the CDA does not flow into and clog the filter. If the proposed Filtration area is used as a sediment trap or basin during the construction phase, the construction notes should clearly specify that, after site construction is complete, the sediment control facility will be dewatered, dredged and re-graded to design dimensions for the post-construction filter.

Step 2. Stormwater should be diverted around Filtration practices as they are being constructed. This is usually not difficult to accomplish for off-line Filtration practices. It is extremely important to keep runoff and eroded sediments away from the filter throughout the construction process. Silt fence or other sediment controls should be installed around the perimeter of the filter, and erosion control fabric may be needed during construction on exposed side-slopes with gradients exceeding 4H:1V. Exposed soils in the vicinity of the Filtration practice should be rapidly stabilized by hydro-seed, sod, mulch, or other method.

Step 3: Assemble construction materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 4: Clear and strip the project area to the desired subgrade.

Step 5: Excavate/grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the Filtration practice.

Step 6: Install the filter structure and check all design elevations (concrete vaults for surface, underground and perimeter sand filters). Upon completion of the filter structure shell, inlets and outlets should be temporarily plugged and the structure filled with water to the brim to demonstrate water tightness. Maximum allowable leakage is 5% of the water volume in a

24-hour period. If the structure fails the test, repairs must be performed to make the structure watertight before any sand is placed into it.

Step 7: Install the gravel, underdrains, and choker layer of the filter.

Step 8: Spread sand across the filter bed in 1 foot lifts up to the design elevation. Backhoes or other equipment can deliver the sand from outside the filter structure. Sand should be manually raked. Clean water is then added until the sedimentation chamber and filter bed are completely full. The facility is then allowed to drain, hydraulically compacting the sand layers. After 48 hours of drying, refill the structure to the final top elevation of the filter bed.

Step 9 (Surface Sand Filters Only): Install the permeable filter fabric over the sand, add a 3-inch topsoil layer and pea gravel inlets, and immediately seed with the permanent grass species. The grass should be watered, and the facility should not be switched on-line until a vigorous grass cover has become established.

Step 10: Stabilize exposed soils on the perimeter of the structure with temporary seed mixtures appropriate for a buffer. All areas above the normal pool should be permanently stabilized by hydroseed, sod, or seeding and mulch.

Step 11: Conduct the final construction inspection, then log the GPS coordinates for each filter facility and submit them for entry into the local maintenance tracking database. Multiple construction inspections are critical to ensure that Filtration practices are properly constructed. Inspections are recommended during the following stages of construction:

- Pre-construction meeting.
- Initial site preparation (including installation of project erosion and sediment controls).
- Excavation/grading to design dimensions and elevations.
- Installation of the filter structure, including the water tightness test.
- Installation of the underdrain and filter bed.
- Check that turf cover is vigorous enough to switch the facility on-line.
- Final inspection (after a rainfall event to ensure that it drains properly and all pipe connections are watertight). Develop a punch list for facility acceptance. Log the Filtration practice's GPS coordinates and submit them for entry into the local BMP maintenance tracking database.

An example construction phase inspection checklist is available in Appendix A of the Manual.

4.2.10. Filtration Practice (FP)

FP-8. Maintenance Criteria

Maintenance is a crucial element that ensures the long-term performance of Filtration practices. Underground sand filters especially are suspect to maintenance issues in that a clogged underground sand filter will not be noticed without intentionally lifting the manhole and observing the status of the filter media. Surface sand filters are much more observable by those trained and untrained alike. Because these are such different practices with different maintenance requirements, this section is divided between surface and underground sand filters

FP-8.1 Surface Sand Filters

Periodic maintenance should be integrated into routine landscape maintenance tasks:

- If landscaping contractors will be expected to perform maintenance (as is likely on commercial, business, or high density residential land uses), their contracts should contain provisions for trained personnel who understand the nuances of stormwater management practices.
- If maintenance is conducted by a homeowner, they should be:

(1) educated about their routine maintenance needs;
(2) understand the long-term maintenance elements; and
(3) be subject to modified maintenance agreements (as described below).

Consider Maintenance during the Design Process

The many design choices made during the design of Filtration practices can be critical to the long term maintenance and effectiveness of the practice. The context of the site along with the maintenance capabilities of the owner(s) should be considered during the design process.

Table FP-5. Design Decisions That Influence Long-Term Maintenance of Filtration Practices

Design Feature	Lower Maintenance	Higher Maintenance
Surface Cover (**Section FP-4.9**) (Surface Sand Filters)	• Sand or gravel surface cover; • Meadow or wildflower cover with native grasses	Grass cover that must be mowed regularly
Surface Cover (**Section FP-4.8**) (Underground Sand Filters)	Sand with no gravel or fabric: (more frequent, but easier maintenance)	Filter fabric and gravel over sand: Less frequent but more complex maintenance
Pre-Treatment (**Section FP-4.2**) (Surface Sand Filters)	Sheet flow entry to filter: pre-treatment cell or grass filter strips with a 2 to 4" drop from the pavement surface	Concentrated flow entry to filter: curb cuts or pipes that accumulate grit and debris at the entry point that must be remove periodically in order to prevent clogging of inlet
Pre-Treatment (**Section FP-4.2**) (Underground Sand Filters)	• Restrict drainage area to impervious cover; • Increase the volume/depth of pre-treatment/ sedimentation chamber normal pool; • Use baffles in pre-treatment/ sedimentation chamber.	Pervious turf and landscaped areas in CDA

FP-8.2 Underground Sand Filters

Underground sand filters must be maintained by qualified individuals with confined space entry credentials. Typical maintenance involves a vacuum truck to remove water from the pre-treatment sedimentation chamber, and other mechanical equipment to lift large volume of gravel, filter fabric, and sand up through the access manhole.

Routine maintenance can include periodically lifting the manhole lid and

FP-8.3 Maintenance Agreements

As with all BMPs, maintenance agreements must be executed between the owner(s) and the local authority to ensure that the practices are maintained and function properly. The agreements will specify the property owner's primary maintenance responsibilities and authorize local agency staff to access the property for inspection or corrective action in the event that proper maintenance is not performed.

Filtration practices must be covered by a drainage easement to allow inspection and maintenance by local authority staff.

FP-8.4 Recommended Maintenance

Maintenance of Filtration practices involves several routine maintenance tasks which are outlined in **Table FP-6**. If the filter treats runoff from a stormwater hotspot, crews may need to test the filter bed media before disposing of the media and trapped pollutants. Petroleum hydrocarbon contaminated sand or filter cloth must be disposed of according to the State of West Virginia's (or local authority's) solid waste disposal regulations. Testing is not needed if the filter does not receive runoff from a designated stormwater hotspot, in which case the media can be safely disposed of in a landfill.

Table FP-6. Recommended Maintenance Tasks For Filtration Practices.

Maintenance Tasks	Frequency
• Remove blockages and obstructions from inflows. Remove trash accumulation in surface sand filters and at storm drain inlets upstream of underground sand filters. • Stabilize contributing drainage area and side-slopes to prevent erosion. Filters with a turf cover should have 95% vegetative cover. • Remove manhole lid of underground sand filter to observe if standing water is present 40 hours after rain event of 0.5 inches or more.	As needed
• Mow grass filter strips and perimeter turf around surface sand filters. Maximum grass heights should be less than 12 inches.	At least four times per growing season
• Check to see if sediment accumulation in the sedimentation chamber has exceeded 6 inches. If so, schedule a cleanout.	2 times per year (may be more or less frequent depending on land use)

Maintenance Tasks	Frequency
• Conduct inspection and cleanup • Dig a small test pit in the filter bed to determine whether the first 1 to 3 inches of sand are visibly discolored and need replacement. • Check to see if inlets and flow splitters are clear of debris and are operating properly. • Check inside of concrete structures and outlets for any evidence of spalling, joint failure, leakage, corrosion, etc. • Ensure that the filter bed is level and remove trash and debris from the filter bed. Sand or gravel covers should be raked to a depth of 3 inches.	Annually
• Replace top sand layer. • Till or aerate surface to improve infiltration/grass cover	Every 5 years
• Corrective maintenance is required any time the sedimentation basin and sediment trap do not draw down completely after 40 hours (i.e., no standing water is allowed).	Upon failure

Regular inspections are critical to schedule sediment removal operations, replace filter media, and relieve any surface clogging. Frequent inspections are especially needed for underground and perimeter sand filters, since they are out of sight and can be easily forgotten. Depending on the level of traffic or the particular land use, a filter system may either become clogged within a few months of normal rainfall, or could possibly last several years with only routine maintenance. Maintenance inspections should be conducted within 24 hours following a storm that exceeds 1/2 inch of rainfall, to evaluate the condition and performance of the Filtration practice. For underground sand filters, this includes simply removing the manhole and verifying that the filter chamber has drawn down within 40 hours. Example maintenance inspection checklists for Filtration practices can be found in **Appendix A of the Manual.**

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SW-1. Introduction

Source: Texas Sea Grant/Texas AgriLife Ext.

Stormwater Wetlands, sometimes called constructed wetlands, are shallow vegetated depressions that receive stormwater inputs for water quality treatment.

Stormwater Wetlands can be used to:

- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs) (see **SW-Table 2**).
- Meet partial or full storage requirements for local stormwater detention standards
- Retrofit existing developed areas
- At this point, Stormwater Wetlands do not achieve average annual runoff reduction, so cannot be used to meet the 1-inch performance standard. However, their water quality performance is solid, and they can be used as an alternative stormwater best management practice (BMP) in certain circumstances and/or downstream from other runoff reduction practices, as approved by the local stormwater program and/or West Virginia Department of Environmental Protection (WVDEP).

Stormwater Wetlands typically are less than 1 foot deep (although they have greater depths at the forebay and in micropools) and possess variable microtopography to promote dense and diverse wetland cover. Runoff from each new storm displaces runoff from previous storms, and the long residence time allows multiple pollutant removal processes to operate. The wetland environment provides an ideal setting for gravitational settling, biological uptake, and microbial activity.

Three basic design variations of the Stormwater Wetland concept are discussed in this section:

1. Wetland basin (Level 1)
2. Multi-cell wetland or pond/wetland combination (Level 2)
3. Subsurface gravel wetland (Modified Level 2)

Figure SW-1 illustrates some typical Stormwater Wetland applications. **Figures SW-2** through **SW-4** are schematics of typical Stormwater Wetland designs. **Table SW-1** describes the features of the three design variations and **Table SW-2** describes the pollutant removal performance of Stormwater Wetlands. **Table SW-3** is a design checklist to help guide the design process for Stormwater Wetland systems.

SW-1.1. Planning the Practice

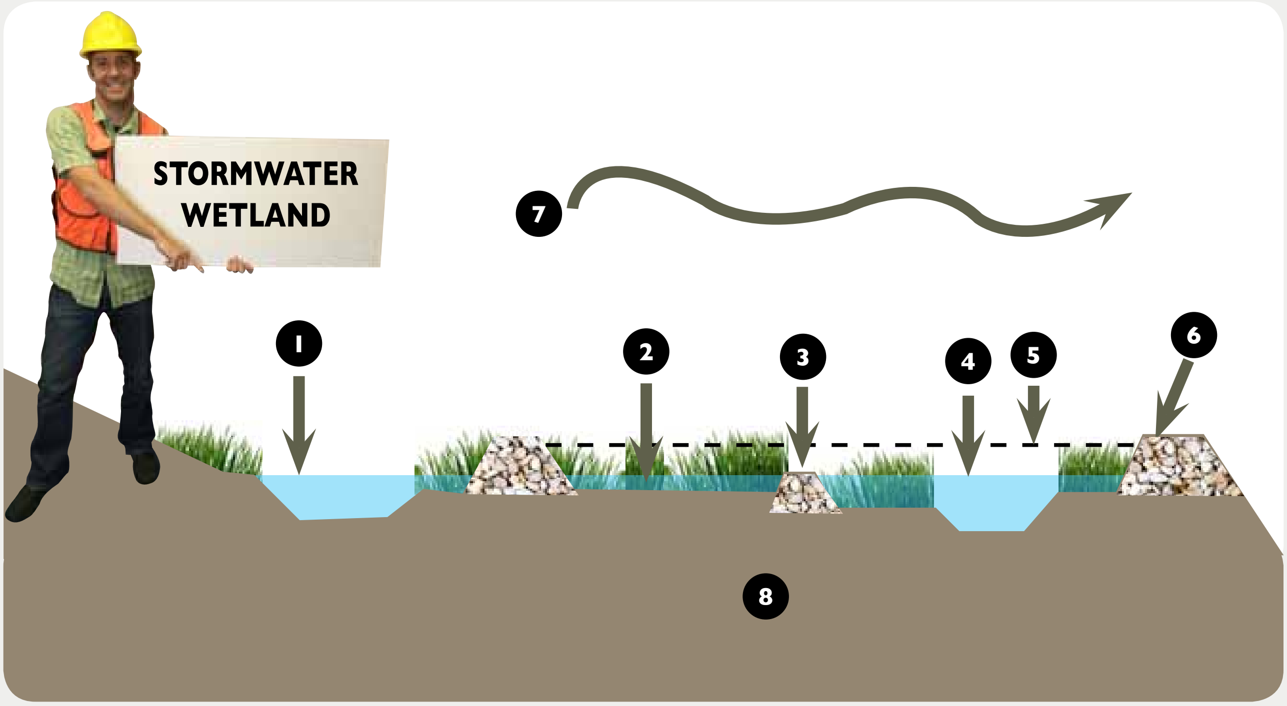
Figure SW-1. Example Applications of Stormwater Wetlands

Typical Stormwater Pond/Wetland System

Typical Multi-Cell Wetland

Subsurface Gravel Wetland
Source: UNH Stormwater Center

Figure SW-2. Schematic Plan and Profile of Stormwater Wetland



1. Pretreatment forebay – Sections SW-4.1, SW-4.4, SW-4.5
2. High marsh zone – Section SW-4.4
3. Weirs & microtopography features – Sections SW-4.1 & SW-4.4
4. Deep pool zones – Section SW-4.4
5. Detention storage above permanent pool – Sections SW-4.1 & SW-4.4
6. Conveyance and overflow, outlet weir, geotechnical testing – Sections SW-4.6 & SW-4.7
7. Geometry of flow through stormwater wetland – Section SW-4.4
8. Stormwater wetland planting – Section SW-4.8

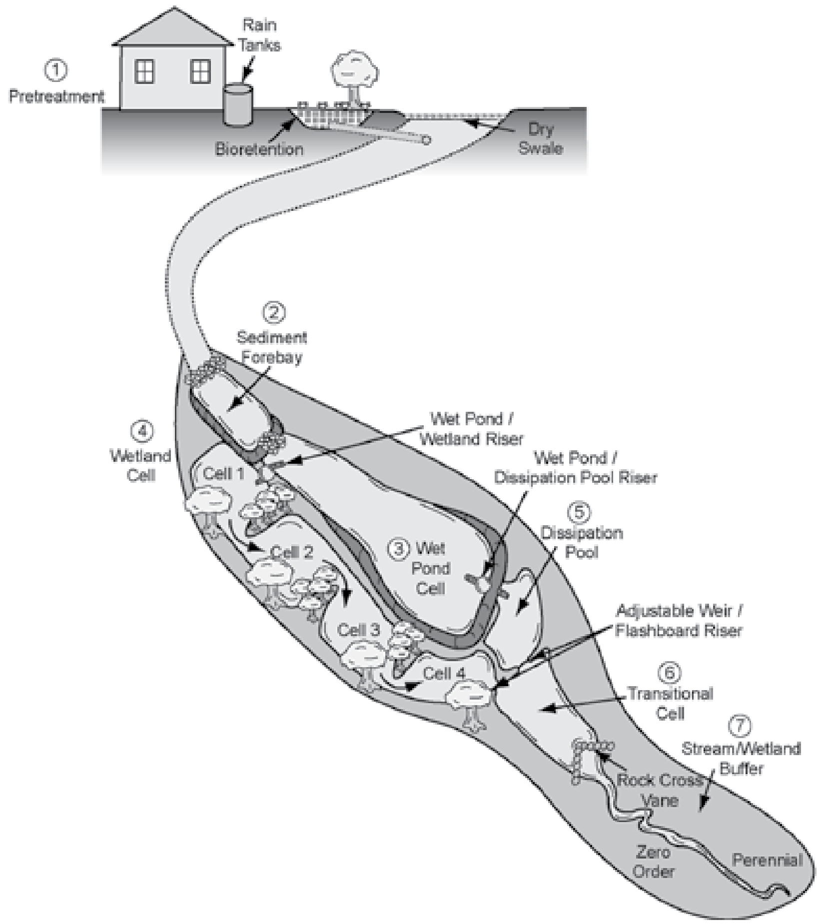


Figure SW-3. Schematic of Pond/Wetland Combination

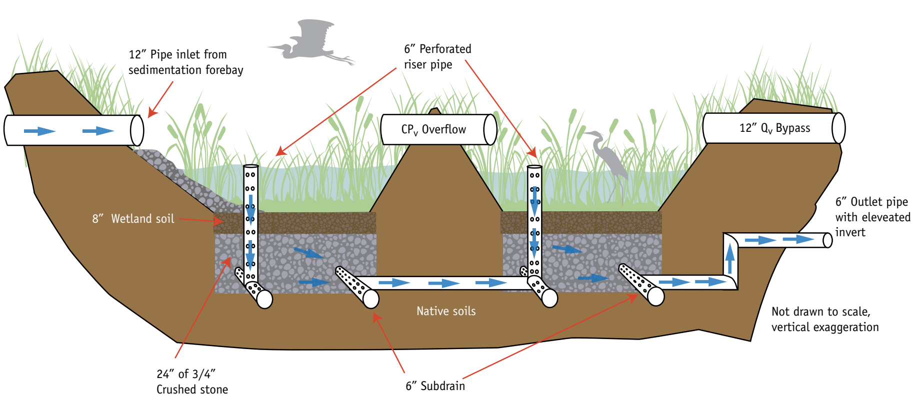


Figure SW-4. Schematic of Subsurface Gravel Wetland (Source: UNH Stormwater Center)

SW-1.2. Stormwater Wetland Design Options & Performance

Two levels of design that enable Stormwater Wetlands to maximize nutrient reduction are shown in **Table SW-1**. At this point there is no runoff volume reduction credit for Stormwater Wetlands. The overall pollutant removal rates of the Level 1 and 2 designs are shown in **Table SW-2**.

Table SW-1. Stormwater Wetland Design Levels: Descriptions & Performance

Design Level	Design Variation Descriptions (See Section 4)	Applications	Performance Achieved Toward Reducing 1" of Rainfall
Level 1	**Wetland Basin** • Single cell (w/ forebay) • Uniform wetland depth • Mean depth more than 1 foot • Surface area less than 3% of contributing drainage area • Design Volume = 1.0 x Target Treatment Volume[1]	Sites where the surface area available for a Stormwater Wetland is limited and where the Level 1 performance can meet water quality goals (see **Table SW-2**).	At this point, research indicates minimal average annual runoff reduction (Hirschman et al., 2008). Consequently, there is no runoff reduction assigned to meeting the 1" standard.
Level 2	**Multi-Cell Wetland or Pond/ Wetland Combination** • Multiple cells (w/ forebay) • Variable depths • Mean depth less than 1 foot • Surface area more than 3% of contributing drainage area • Design Volume = 1.5 x Target Treatment Volume[1]	Sites with more surface area available and where enhanced water quality performance is needed to meet water quality goals.	
	Subsurface Gravel Wetland • 2 cells (w/ forebay) • Saturated gravel layer • Minimum 24" gravel sub-layer • Design and sizing as per UNHSC (2009) and RIDEM (2010)	Sites that require enhanced nutrient removal, especially for nitrogen.	

[1] The Target Treatment Volume (Tv) is the volume associated with 1" of rainfall for the contributing drainage area (CDA). See the Design Compliance Spreadsheet for calculations of the Tv. The Design Volume for a constructed wetland can be the entire Tv or some proportion of it if upstream runoff reduction practices are used.

Table SW-2. Pollutant Removal Performance Values for Stormwater Wetlands

Design Level	Total Suspended Solids (TSS)[1]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN)[1]
Level 1	TSS = 50%	TP = 50% TN = 25%
Level 2: Multi-Cell or Pond/Wetland	TSS = 80%	TP = 75% TN = 55%
Modified Level 2: Subsurface Gravel Wetland	TSS = 95%[2]	TP = 55%[2] Dissolved Inorganic N = 95%[2]

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration (EMC) as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008). Since Stormwater Wetlands do not have an assigned runoff reduction rate, TR = EMC reduction.
[2]These values are provisional as derived from UNHSC (2007) and USEPA (2008).

SW-1.3. Stormwater Wetland Design Checklist

Table SW-3. Stormwater Wetland Design Checklist

CHECKLIST

This checklist will help the designer with the necessary design steps for Stormwater Wetlands.

- ☐ Ascertain the regulatory context of using a Stormwater Wetland, how the wetland will be used in conjunction with runoff reduction practices, and how the 1" performance standard can be met on the site or partially waived to allow a water quality treatment practice in conjunction with or in lieu of runoff reduction practices. This will likely require consultation with the local program and West Virginia Department of Environmental Protection (WVDEP).
- ☐ Check feasibility for site – **Section SW-3**
- ☐ Determine whether a Level 1 or Level 2 design is best for the site. Use Level 2 unless site constraints necessitate the Level 1 design – **Table SW-1**
- ☐ Complete Design Compliance Spreadsheet to plan and confirm required Stormwater Wetland sizing (Target Treatment Volume), additional practices needed, and overall site compliance – Design Compliance Spreadsheet & **Chapter 3** of Manual
- ☐ Check Stormwater Wetland sizing guidance and make sure there is an adequate footprint on the site– SW-Sections 4.2 & SW-4.3
- ☐ Check design adaptations appropriate to the site – Section SW-6
- ☐ Design Stormwater Wetland in accordance with design criteria and typical details – Sections SW-2 & SW-4
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence notes

4.2.11. Stormwater Wetlands (SW)

SW-2. Typical Details

Typical details for Stormwater Wetland variations (excluding the subsurface gravel wetland) are provided in **Figures SW-5 through SW-7**.

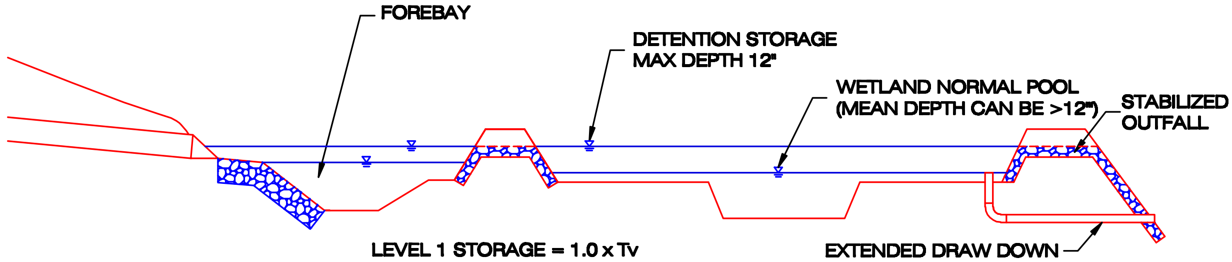


Figure SW-5. Typical profile for Level 1 Design

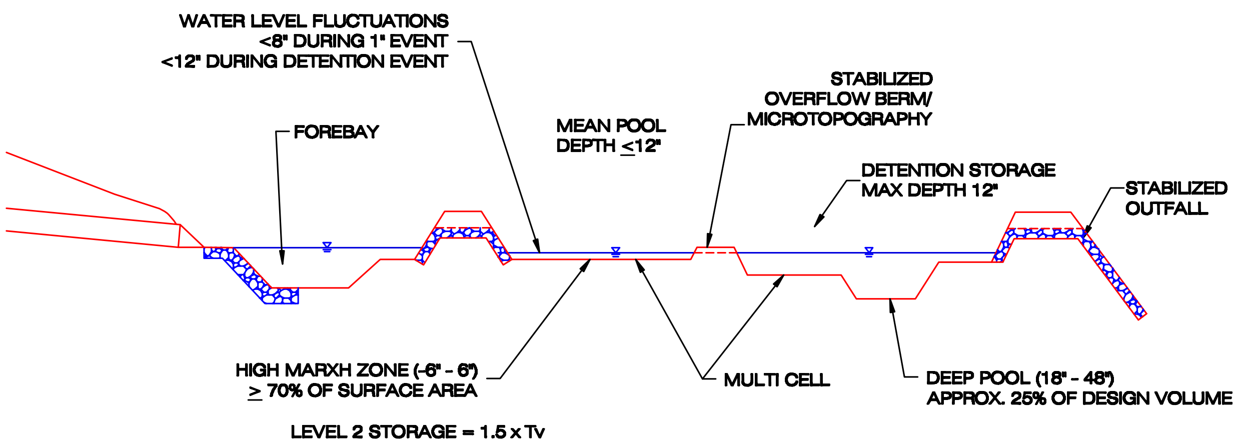


Figure SW-6. Typical profile for Level 2 Design

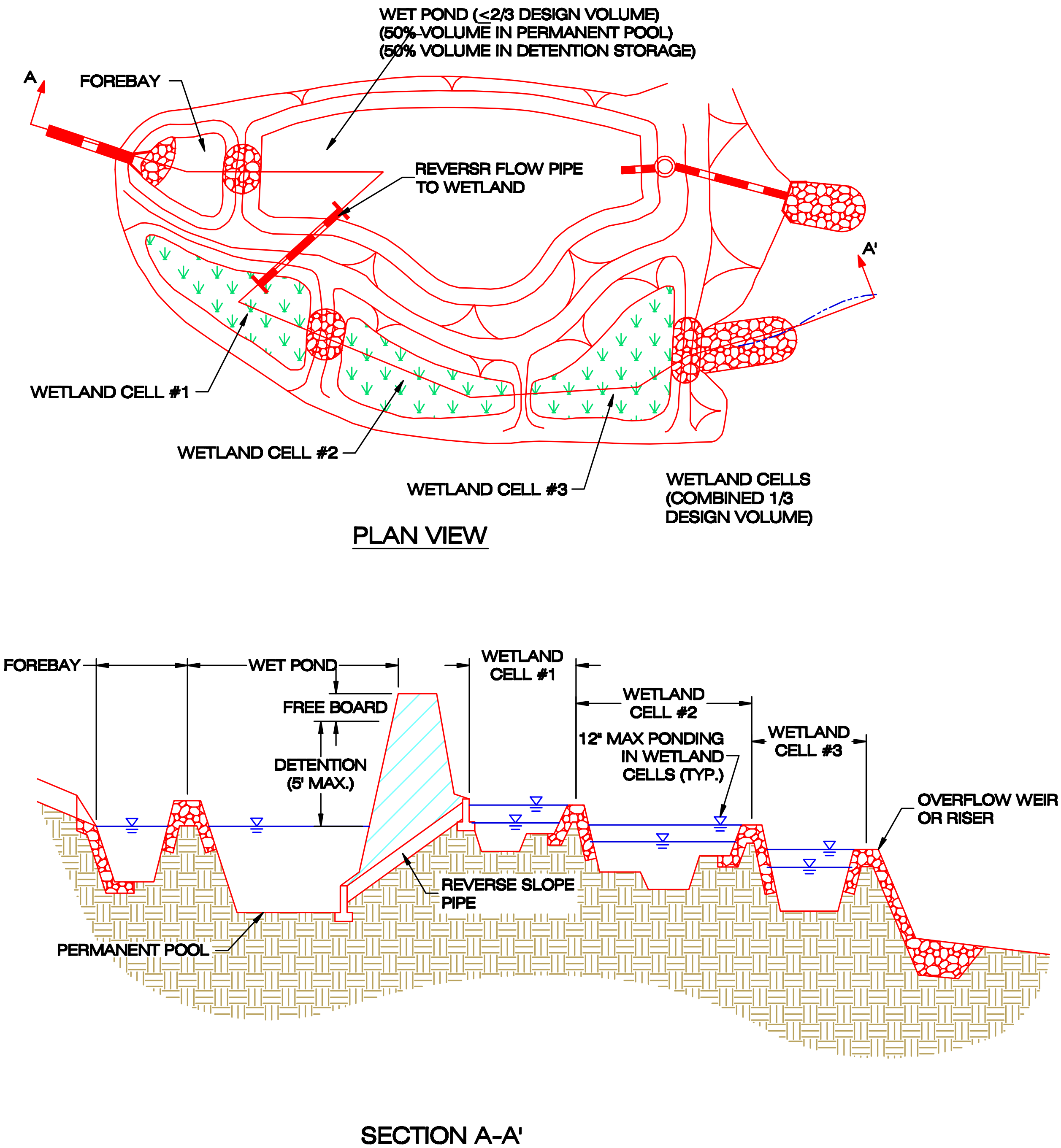


Figure SW-7. Typical Plan and Section for Pond/Wetland Combination

4.2.11. Stormwater Wetlands (SW)

SW-3. Feasibility Criteria and Design Considerations

Stormwater Wetland designs are subject to the following site constraints:

Adequate Water Balance. Wetlands must have enough water supplied from groundwater, runoff or baseflow so that the permanent pools will not draw down by more than 2 feet after a 30-day summer drought. A simple water balance calculation must be performed using the equation provided in Section SW-4.3., Water Balance.

Contributing Drainage Area (CDA). The CDA must be large enough to sustain a permanent water level within the Stormwater Wetland. If the only source of wetland hydrology is stormwater runoff, then several dozen acres of drainage area are typically needed to maintain constant water elevations. Smaller drainage areas are acceptable if the bottom of the wetland intercepts the groundwater table or if the designer or approving agency is willing to accept periodic wetland drawdown. Stormwater Wetlands typically have a drainage area of 10 to 25 acres.

Space Requirements. Stormwater Wetlands normally require a footprint that takes up about 3% of the contributing drainage area, depending on the average depth of the wetland and the extent of its deep pool features.

Steep Slopes. A design alternative to the Stormwater Wetland in steep terrain is the Regenerative Stormwater Conveyance (RSC) System (see Specification 4.2.7, Regenerative Stormwater Conveyance). The RSC can be used to bring stormwater down steeper grades through a series of step pools. This can serve to bring stormwater down outfalls where steep drops can create design challenges. Alternately, Stormwater Wetlands on steep sites can be split into various cells with adequate conveyance between cells in order to take advantage of flatter spots on the site.

Available Hydraulic Head. The depth of a Stormwater Wetland is usually constrained by the hydraulic head available on the site. The bottom elevation is fixed by the elevation of the existing downstream conveyance system to which the wetland will ultimately discharge. Because Stormwater Wetlands are typically shallow, the amount of head needed (usually a minimum of 2 to 4 feet) is typically less than for wet ponds.

Minimum Setbacks. Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, utilities, and wells. As a general rule, the edges of Stormwater Wetlands should be located at least 10 feet away from property lines, 25 feet from building foundations, 50 feet from septic system fields, and 100 feet from drinking water wells.

Depth to Water Table. The depth to the groundwater table is not a major constraint for Stormwater Wetlands, since a high water table can help maintain wetland conditions. However, designers should keep in mind that high groundwater inputs may reduce pollutant removal rates and increase excavation costs.

Soils. Soil tests should be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed wetland. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most HSG A soils and some HSG B soils will require a liner.

Trout Streams. The use of Stormwater Wetlands in watersheds containing trout streams is generally not recommended due to the potential for stream warming, unless (1) other upland runoff reduction practices are fully utilized, and (2) a linear/mixed wetland design using trees as part of the planting plan is applied to minimize stream warming.

Use of or Discharges to Natural Wetlands. Stormwater Wetlands should not be located within jurisdictional waters, including wetlands. Theoretically, this can be done by obtaining a section 404 permit from the appropriate federal regulatory agency, but this approach is discouraged strongly. In addition, designers should investigate the status of adjacent wetlands to determine if the discharge from the Stormwater Wetland will change the hydroperiod of an immediately downstream natural wetland (see Cappiella et al., 2005 for guidance on minimizing stormwater discharges to existing wetlands).

Regulatory Status. Stormwater Wetlands built for the express purpose of stormwater treatment are not considered jurisdictional wetlands in most regions of the country, but designers should check with their wetland regulatory authorities to ensure this is the case.

Perennial Streams. Locating a Stormwater Wetland along or within a perennial stream will require both Section 401 and Section 404 permits from the state or federal regulatory authority. As with natural wetlands, this design approach is discouraged strongly. If perennial streams are involved, off-line designs that remove the Stormwater Wetland from the stream channel should be used.

Community and Environmental Concerns. Stormwater Wetland designs should strive to address the following:

- Aesthetics and Habitat. Stormwater Wetlands can create wildlife habitat and can also become an attractive community feature. Designers should think carefully about how the wetland plant community will evolve over time, since the future plant community seldom resembles the one initially planted. Invasive control is a major concern with the long-term management of Stormwater Wetlands.
- Existing Forests. Given the large footprint of a Stormwater Wetland, there is a strong chance that the construction process may result in extensive tree clearing. The designer should preserve mature trees during the facility layout, and may consider creating a wooded wetland (see Cappiella et al., 2006).
- Safety Risk. Stormwater Wetlands are safer than other types of ponds, although forebays and micropools should be designed with aquatic benches to reduce safety risks.
- Mosquito Risk. Mosquito control can be a concern for Stormwater Wetlands if they are under-sized or have a small CDA. Deepwater zones serve to keep mosquito populations in check by providing habitat for fish and other pond life that prey on mosquito larvae. Few mosquito problems are reported for well designed, properly-sized and frequently-maintained Stormwater Wetlands; however, no design can eliminate them completely. Simple precautions can be taken to minimize mosquito breeding habitat within Stormwater Wetlands, for example, constant inflows, benches that create habitat for natural predators, and constant pool elevations (MSSC, 2005).

4.2.11. Stormwater Wetlands (SW)

SW-4. Design Criteria

SW-4.1. Design Variations

Stormwater Wetlands are designed based on three major factors: (1) the desired plant community (an emergent wetland as in Level 1 design; a mixed emergent and forest wetland; or an emergent/pond combination as in Level 2 design); (2) the contributing hydrology (groundwater, surface runoff or dry weather flow); and (3) the landscape position (linear or basin) (Cappiella, et al., 2008).

To simplify design, three basic design variations are presented for Stormwater Wetlands:

1. Wetland basin – Level 1 design
2. Multi-cell wetland or pond/wetland combination – Level 2 design
3. Subsurface gravel wetland – modified Level 2 design

Wetland Basin (Level 1). Consists of a single cell (including a forebay) with a relatively uniform water depth. A portion of the Design Volume can be in the form of detention storage above the wetland pool, if required by local stormwater detention standards. However, this storage depth should not exceed 12 inches. Wetland basins can be used at the terminus of a storm drain pipe or open channel after upland opportunities for runoff reduction have also been applied.

Multi-Cell Wetland and Multi-Cell Pond/Wetland Combination systems (Level 2). These designs provide more treatment by creating a longer and sinuous flow path, more residence time, and more contact with wetland vegetation. The Design Volume is also increased for the Level 2 design. As with Level 1, detention storage above the permanent pool is limited to 12 inches. The pond/wetland combination design involves a wet pond cell in parallel or series with Stormwater Wetland cells. Small storms (e.g., those associated with 1 inch of rainfall) flow through the wetland cells while diverting the larger storm runoff into the wet pond cell. This is so the wetland cells are not subject to the higher water level fluctuations associated with rising and falling detention storage.

Further guidance on the pond/wetland combination is provided below:

- The wet pond cell has three primary functions: (1) pre-treatment to capture and retain heavy sediment loads or other pollutants (such as trash, oils and grease, etc.); (2) provisions for an extended supply of flow to support wetland conditions between storms; and (3) storage volume for larger storms if required by local detention requirements.
- The discharge from the pond cell to the wetland cells should ideally consist of a reverse slope-pipe. The design may also consist of an additional smaller pipe with a valve or other control to allow for hydrating the wetland with a trickle flow from the wet pond normal pool during dry periods.

As an alternative, the water quality storm can be diverted into the wetland cell for treatment by using a low flow diversion sized for the Tv peak flow rate, while the larger storms are routed into the wet pond cell.

- The wetland should be divided into sub-cells to cascade down the grade differential or slope. Ideally, different pool depths are established with sand berms (anchored by rock at each end), back-filled coir fiber logs, or forested peninsulas (extending as wedges across 90% of the wetland width). Grade drops between cells should be stabilized as needed based on the design flow and velocity.

Subsurface Gravel Wetland (Modified Level 2). This design variation consists of a sediment forebay followed by a series of horizontal flow-through cells designed to retain and filter the entire Design Volume (UNHSC, 2009). Nutrient removal occurs as stormwater passes through wetland plants and soil, then a microbe-rich saturated gravel bed. Runoff greater than the Design Volume overflows the wetland via an emergency spillway, after a short period of detention. See UNHSC (2009) and RIDEM (2010) for more detailed design specifications for subsurface gravel wetlands.

It should be noted that the remainder of this specification applies to the first two design variations. The design references listed above for subsurface gravel wetlands should be consulted for the design of those systems, since they are a unique subset of Stormwater Wetlands.

SW-4.2. Stormwater Wetland Sizing for Water Quality Treatment

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a BMP plan:

Target Treatment Volume (Tv) = Volume associated with managing 1" of rainfall based on the size and land cover of the CDA, as determined by the Design Compliance Spreadsheet. Any given BMP may treat the full Tv, or only part of it if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on storage in the practice, as prescribed in the BMP specification. Note that, while Stormwater Wetlands can be designed to store temporarily a particular Dv, they do not meet the MS4 General Permit criteria to "keep and manage on-site the first one-inch of rainfall" and thus do not have an associated runoff reduction credit and do not contribute to reducing the overall Tv. However, Stormwater Wetlands do achieve pollutant removal rates as outlined in Table SW-2. Designers should check with the local plan approval authority on use and approval of Stormwater Wetlands as part of an overall BMP plan.

Since Stormwater Wetlands are usually the terminal practice in a treatment train (e.g., the farthest downstream), the Dv is the remaining volume after upstream runoff reduction practices are employed to reduce the Tv.

See **Chapter 3** for more information on the runoff reduction design methodology.

For the purposes of this sizing section, the sizing relates to the Dv of the Stormwater Wetland being designed.

Stormwater Wetlands should be designed to capture and treat the remaining Tv discharged from upstream runoff reduction practices, as ascertained using the Design Compliance Spreadsheet (see **Chapter 3**). As described in the text box above, this volume is known as the Dv.

To qualify for the higher nutrient reduction rates associated with the Level 2 designs, Stormwater Wetlands must have a Design Volume that is 50% greater than the Level 1 design. Research has shown that larger Stormwater Wetlands with longer residence times enhance nutrient removal rates. Design Volume credit can be taken for the following:

Wetland Basin – Level 1 design: Dv = 1.0 x Tv as reduced byupstream runoff reduction practices

- The entire water volume below the normal pool (including deep pools);
- Detention storage up to 12 inches above the normal pool; and
- Any void storage within a submerged rock, sand or stone layer within the wetland.

Multi-Cell Wetland or Pond/Wetland Combination – Level 2 design: Dv = 1.5 x Tv as reduced by upstream runoff reduction

- The entire water volume below the normal pool of each wetland cell (including deep pools).
- Any void storage within a subsurface rock, sand or stone layer within the wetland cells.
- For pond/wetland combinations, up to 2/3 of the total required Design Volume can be provided in the pond cell, as follows:
    - o A minimum of ½ of the volume allocated to the pond cell is in the permanent pool (in other words, up to 1/3 of the total Design Volume).
    - o The remaining volume allocated to the pond cell can be in the form of detention storage provided above the permanent pool.

Subsurface Gravel Wetland – Level 2 design [Sizing as per UNHSC (2009) and RIDEM (2010)]:

- All storage within forebays, wetland cells, and gravel beds.

SW-4.3 Water Balance: Sizing for Minimum Pool Depth

Initially, it is recommended that there be no minimum drainage area requirement for the system, although it may be necessary to calculate a water balance for the wet pond cell, especially when its CDA is less than 10 acres.

Adequate Water Balance is Essential for Success of Stormwater Wetlands

The number one design factor for Stormwater Wetlands is water balance, and this may not be entirely dependent on the size of the CDA. Stormwater Wetlands must have an adequate supply of water from runoff, baseflow, and/or groundwater in order to maintain water levels during dry periods.

If the hydrology for the Stormwater Wetland is not supplied by groundwater or dry weather flow inputs, a simple water balance calculation must be performed, using **Equation SW-1** (Hunt et al., 2007), to assure the deep pools will not go completely dry during a 30-day summer drought.

Equation SW-1. The Hunt Water Balance Equation for Acceptable Water Depth in a Stormwater Wetland

$$DP = RF_m * EF * WS/WL - ET - INF - RES$$

Where:

DP	=	Depth of pool (inches)
RFm	=	Monthly rainfall during drought (inches)
EF	=	Fraction of rainfall that enters the Stormwater Wetland (CDA * Rv)
WS/WL	=	Ratio of CDA to wetland surface area
ET	=	Summer evapotranspiration rate (inches; assume 8 or locally appropriate number)
INF	=	Monthly infiltration loss (assume 7.2 inches @ 0.01 inch/hour)
RES	=	Reservoir of water for a factor of safety (assume 6 inches)

Using **Equation SW-1**, setting the groundwater and (dry weather) base flow to zero and assuming a worst case summer rainfall of 0 inches, the minimum depth of the pool calculates as follows:

Equation SW-2. Minimum Depth of the Permanent Pool

$$\text{Depth of Pool (DP)} = 0\text{''}\ (RF_m) - 8\text{''}\ (ET) - 7.2\text{''}\ (INF) - 6\text{''}\ (RES) = 21.2 \text{ inches}$$

Therefore, unless there is other input, such as base flow or groundwater, the minimum depth of the pool **should be at least 21 to 22 inches**. This condition automatically kicks the design to a Level 1 design.

SW-4.4. Design Geometry for Stormwater Wetlands

Research and experience have shown that the internal design geometry and depth zones are critical in maintaining the pollutant removal capability and plant diversity of Stormwater Wetlands. Wetland performance is enhanced when the wetland has multiple cells, longer flowpaths, and a high ratio of surface area to volume. Whenever possible, Stormwater Wetlands should be irregularly shaped with long, sinuous flow paths. The following design elements are required for Stormwater Wetlands:

Multiple-Cell Wetlands (Level 2 designs). When a Level 2 design is selected, the wetland should be divided into at least four internal sub-cells of different elevations: the forebay, at least two wetland cells, and a micro-pool outlet. The first cell (the forebay) is deeper and is used to receive runoff from the pond cell or the inflow from a pipe or open channel and distribute it evenly into successive wetland cells (see **Section SW-4.5**). The purpose of the wetland cells is to create an alternating sequence of aerobic and anaerobic conditions to maximize nitrogen removal. The fourth wetland cell is located at the discharge point and serves as a micro-pool with an outlet structure or weir.

Each wetland sub-cell can be differentiated by sand berms (anchored by rock at each end), back-filled coir fiber logs, or forested peninsulas extending as wedges across 95% of the wetland cell width (see section below on micro-topography). If there are elevation drops greater than 1 foot between cells, then the designer should consider using an earthen berm with a spillway, concrete weir, gabion baskets, or other means that provide adequate freeboard to pass expected peak rates (these approaches also applicable to the forebay and micro-pool). In addition, stable conveyance between cells should be provided based on the elevation change and expected velocities.

Micro-Topographic Features. While the slope profile within individual wetland cells should generally be flat from inlet to outlet, Stormwater Wetlands must have internal structures that create variable micro-topography. This is defined as a mix of above-pool vegetation, shallow pools, and deep pools that promote dense and diverse vegetative cover. Designers will need to incorporate at least two of the following internal design features to meet the microtopography requirements for Level 2 designs:

- Tree peninsulas, high marsh wedges or rock filter cells configured perpendicular to the flow path.
- Tree islands above the normal pool elevation and maximum detention zone, formed by coir fiber logs.
- Inverted root wads or large woody debris.
- Gravel diaphragm layers within high marsh zones.
- Cobble sand weirs.

Detention Storage Ponding Depth. Where a Stormwater Wetland basin (Level 1 design) incorporates detention storage for larger storms, the detention elevation above the permanent pool should be 1 vertical foot or less.

Where a Level 2 design is used, the detention storage limits are as follows:

- Multi-cell wetlands must be designed so that the water level fluctuation associated with the maximum "Design Volume" storm (a 1-inch rainfall event) is limited to 6 to 8 inches.
- The maximum water level fluctuation during the larger design storm associated with local detention requirements (as applicable) should be limited to 12 inches in the wetland cells. This can be achieved by using a long weir structure capable of passing large flows at relatively low hydraulic head. If this standard cannot be met within the Stormwater Wetland footprint, the designer should use the pond/wetland combination design or an "off-line" design whereby the wetland receives only flow associated with the Design Volume, and larger flows are diverted to other detention facilities.
- For the pond/wetland combination, the maximum detention storage depth may be up to 5 feet above the wet pond cell permanent pool (but not the wetland cells).

Pool Depths. Level 1 wetland designs may have a mean pool depth greater than 1 foot. Level 2 wetland cells must have a mean pool depth less than or equal to 1 foot.

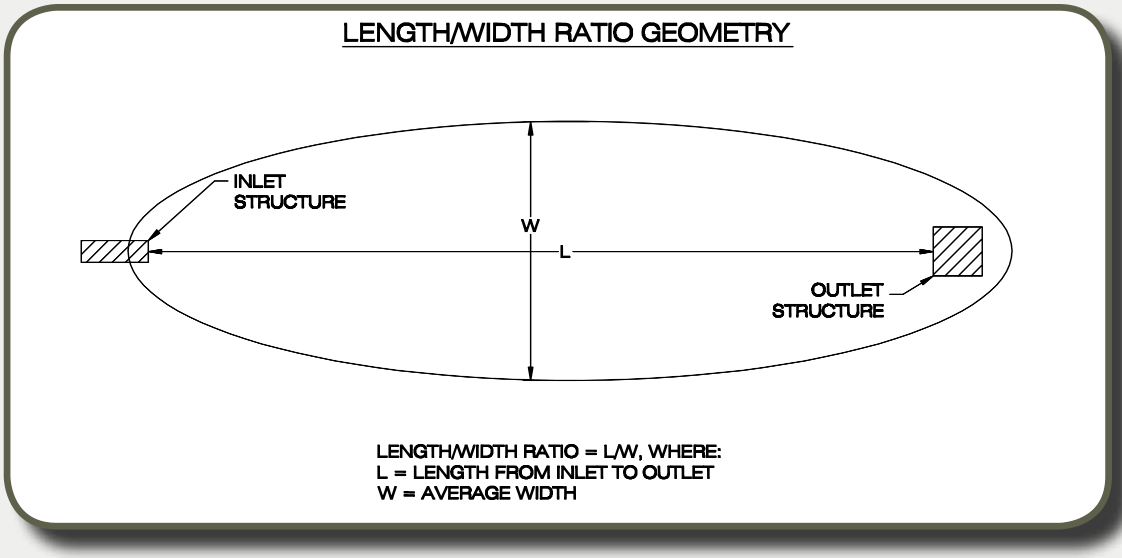
Deep Pools. Approximately 25% of the wetland Design Volume must be provided in at least three deeper pools – located at the inlet (forebay), center, and outlet (micro-pool) of the wetland. Approximately 60% of this overall deep pool volume should be allocated to the forebays. Each deep pool should have a depth of 18 to 48 inches. Refer to sizing based on water balance in **Sections SW-4.2 and SW-4.3** for additional guidance on the minimum depth of the deep pools.

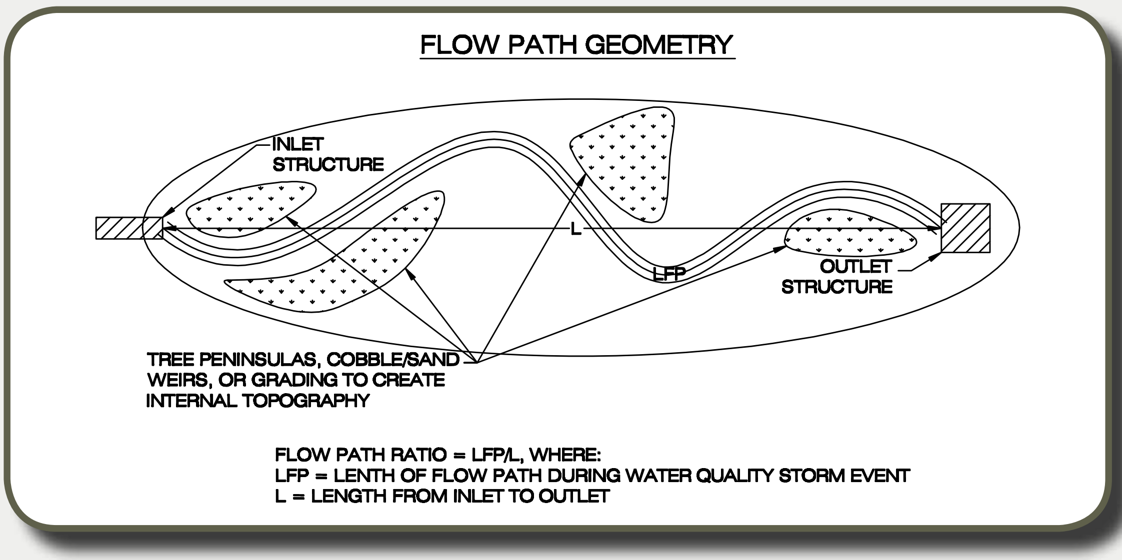
High Marsh Zone. Approximately 70% of the wetland surface area must exist in the high marsh zone (-6 inches to +6 inches relative to the normal pool elevation).

Transition Zone. The low marsh zone (-6 to -18 inches below the normal pool elevation) is **no longer an acceptable wetland zone**, and is only allowed as a short transition zone from the deeper pools to the high marsh zone. In general, this transition zone should have a maximum slope of 5H:1V (or preferably flatter) from the deep pool to the high marsh zone. It is advisable to install biodegradable erosion control fabrics or similar materials during construction to prevent erosion or slumping of this transition zone.

Flow Path. In terms of the flow path, there are two design objectives:

- The **overall flow path through the wetland** can be represented as the length-to-width ratio and/or the flow path ratio (see **Figure SW-8**). At least one of these ratios must be at least 2:1 for Level 1 designs and 3:1 for Level 2 designs.
- The **shortest flow pat**h represents the distance from the closest inlet to the outlet (see **Figure SW-8, bottom**). The ratio of the shortest flow path to the overall length must be at least 0.5 for Level 1 designs and 0.8 for Level 2 designs. In some cases – due to site geometry, storm sewer infrastructure, or other factors – some inlets may not be able to meet these ratios. However, the drainage area served by these "closer" inlets should constitute no more than 20% of the total CDA.





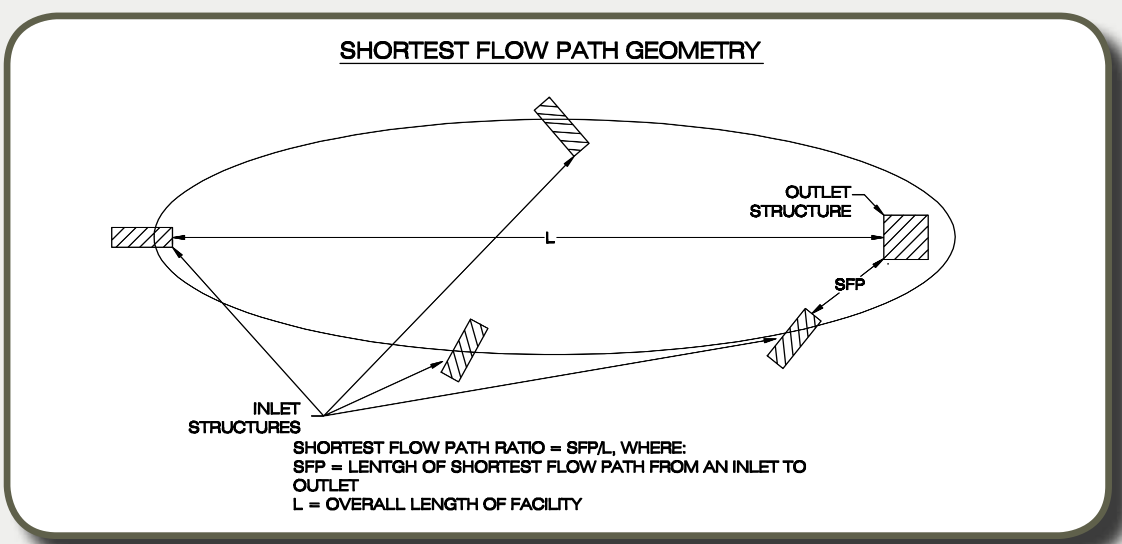


Figure SW-8. Design geometry factors: (1) Length/Width Ratio (top), (2) Flow Path Ratio (middle), and (3) Shortest Flow Path Ratio.

Side Slopes. Side slopes for the wetland should generally have gradients of 4H:1V to 5H:1V. Such mild slopes promote better establishment and growth of the wetland vegetation. They also contribute to easier maintenance and a more natural appearance.

SW-4.5. Pre-treatment Forebay

Sediment forebays are considered an integral design feature of all Stormwater Wetlands (including Level 1 designs). A forebay must be located at every major inlet (see definition below) to trap sediment and preserve the capacity of the main wetland treatment cells. Other forms of pre-treatment for sheet flow and concentrated flow for minor inflow points should be designed consistent with pretreatment criteria found in **Specification 4.2.3**, Bioretention.

The following criteria apply to forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel conveying runoff from least 10% of the Stormwater Wetland's CDA.
- The forebay consists of a separate cell in both the Level 1 and Level 2 designs, and it is formed by an acceptable barrier (e.g., an earthen berm, concrete weir, gabion baskets, etc.).
- The forebay should be a maximum of 4 feet deep (or as determined by the summer drought water balance, Equations SW-1 and SW-2) near the inlet, and then transition to a 1 foot depth at the entrance to the first wetland cell.
- The forebay should be equipped with a variable width aquatic bench, which is a shallow vegetated bench around the perimeter that provides both habitat and safety features. The aquatic bench should be 4 to 6 feet wide at a depth of approximately 1 foot below the water surface at its inner edge (closest to the deep water), transitioning to zero depth at grade.
- The relative size of individual forebays should be proportional to the percentage of the total inflow to the wetland. Similarly, any outlet protection associated with the end section or end wall should be designed according to state or local design standards.
- The bottom of the forebay may be hardened (e.g., with concrete, asphalt, or grouted riprap) to make sediment removal easier.
- The forebay should be equipped with a metered rod in the center of the pool (as measured lengthwise along the low flow water travel path) for long-term monitoring of sediment accumulation.

SW-4.6. Conveyance and Overflow

Since most Stormwater Wetlands are on-line facilities, they need to be designed to safely pass the maximum design storm (e.g., the 10-year and 100-year design storms).

While many different options are available for setting the normal pool elevation, it is strongly recommended that removable flashboard risers be used, given their greater operational flexibility to adjust water levels following construction (see Hunt et al, 2007). Also, a weir can be designed to accommodate passage of the larger storm flows at relatively low ponding depths.

SW-4.7. Geotechnical Testing

Soil borings should be taken below the proposed embankment, in the vicinity of the proposed outlet area, and in at least two locations within the planned wetland treatment area. Soil boring data is needed to (1) determine the physical characteristics of the excavated material; (2) determine its adequacy for use as structural fill or spoil; (3) provide data for the designs of outlet structures (e.g., bearing capacity and buoyancy); (4) determine compaction/composition needs for the embankment; (5) define the depth to groundwater and/or bedrock; and (6) evaluate potential infiltration losses (and the consequent need for a liner).

SW-4.8. Stormwater Wetland Planting Criteria

An initial wetland planting plan is required for any Stormwater Wetland and should be jointly developed by the engineer and a wetlands expert or experienced landscape architect. The plan should outline a detailed schedule for the care, maintenance and possible reinforcement of vegetation in the wetland and its buffer for up to 10 years after the original planting.

The plan should outline a realistic, long-term planting strategy to establish and maintain desired wetland vegetation. The plan should indicate how wetland plants will be established within each inundation zone (e.g., wetland plants, seed-mixes, volunteer colonization, and tree and shrub stock) and whether soil amendments are needed to get plants started. At a minimum, the plan should contain the following:

- Plan view(s) with topography at a contour interval of no more than 1 foot and spot elevations throughout the cell showing the wetland configuration, different planting zones (e.g., high marsh, deep water, upland), microtopography, grades, site preparation, and construction sequence.
- A plant schedule and planting plan specifying emergent, perennial, shrub and tree species, quantity of each species, stock size, type of root stock to be installed, and spacing. To the degree possible, the species list for the Stormwater Wetland should contain plants found in similar local wetlands.

The local regulatory authority will usually establish any more specific vegetative goals to achieve in the wetland landscaping plan. The following general guidance is provided:

Use Native Species Where Possible. Table SW-4 provides a list of common native shrub and tree species and **Table SW-5** provides a list of common native emergent, submergent and perimeter plant species, all of which have proven to do well in Stormwater Wetlands in the mid-Atlantic region and are generally available from most commercial nurseries (for a list of some of these nurseries, see **Appendix F**). Other native species can be used that appear in state-wide plant lists. The use of native species is strongly encouraged, but in some cases, non-native ornamental species may be added as long as they are not invasive. Invasive species such as cattails, Phragmites and purple loosestrife should never be planted. See **Appendix F** for a more comprehensive plant list for stormwater management facilities, including stormwater wetlands.

Match Plants to Inundation Zones. The various plant species shown in **Tables SW-4** and **SW-5** should be matched to the appropriate inundation zone. The first four inundation zones are particularly applicable to Stormwater Wetlands, as follows:

- o **Zone 1:** -6 inches to -12 below the normal pool elevation
- o **Zone 2:** -6 inches to the normal pool elevation)
- o **Zone 3:** From the normal pool elevation to + 12 inches above it)
- o **Zone 4:** +12 inches to + 36 inches above the normal pool elevation (i.e., above detention storage zone)

Aggressive Colonizers. To add diversity to the wetland, 5 to 7 species of emergent wetland plants should be planted, using at least four emergent species designated as aggressive colonizers (shown in bold in **Table SW-5**). No more than 25% of the high marsh wetland surface area needs to be planted. If the appropriate planting depths are achieved, the entire wetland should be colonized within three years. Individual plants should be planted 18 inches on center within each single species "cluster."

Table SW-4. Popular and Versatile Native Trees and Shrubs for Stormwater Wetlands

Shrubs		Trees	
Common & Scientific Names	Zone[1]	Common & Scientific Names	Zone[1]
Button Bush (Cephalanthus occidentalis)	2, 3	Atlantic White Cedar (Charnaecyparis thyoides)	2, 3
Common Winterberry (Ilex verticillatta)	3, 4	Bald Cypress (Taxodium distichum)	2, 3
Elderberry (Sambucus canadensis)	3	Black Willow (Salix nigra)	3, 4
Indigo Bush (Amorpha fruticosa)	3	Box Elder (Acer Negundo)	2, 3
Inkberry (Ilex glabra)	2, 3	Green Ash (Fraxinus pennsylvanica)	3, 4
Smooth Alder (Alnus serrulata)	2, 3	Grey Birch (Betula populifolia)	3, 4
Spicebush (Lindera benzoin)	3, 4	Red Maple (Acer rubrum)	3, 4
Swamp Azalea (Azalea viscosum)	2, 3	River Birch (Betula nigra)	3, 4
Swamp Rose (Rosa palustris)	2, 3	Swamp Tupelo (Nyssa biflora)	2, 3
Sweet Pepperbush (Clethra ainifolia)	2, 3	Sweetbay Magnolia (Magnolia virginiana)	3, 4

Trees (continued, Table SW-4)	
Common & Scientific Names	**Zone**[1]
Sweetgum (Liquidambar styraciflua)	3, 4
Sycamore (Platanus occidentalis)	3, 4
Water Oak (Quercus nigra)	3, 4
Willow Oak (Quercus phellos)	3,4

[1]Zone 1: -6 to -12 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 to +36 inches; above detention storage zone

Table SW-5. Popular and Versatile Native Emergent and Submergent Vegetation for Stormwater Wetlands

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Arrow Arum (Peltandra virginica)	2	Emergent	Up to 1 ft.	High; berries are eaten by wood ducks	Full sun to partial shade
Broad-Leaf Arrowhead (Duck Potato) (Saggitaria latifolia)	2	Emergent	Up to 1 ft.	Moderate; tubers and seeds eaten by ducks	Aggressive colonizer

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Blueflag Iris* (Iris versicolor)	2, 3	Emergent	Up to 6 in.	Limited	Full sun (to flower) to partial shade
Broomsedge (Andropogon virginianus)	2, 3	Perimeter	Up to 3 in.	High; songbirds and browsers; winter food and cover	Tolerant of fluctuating water levels and partial shade
Bulltongue Arrowhead (Sagittaria lancifolia)	2, 3	Emergent	0-24 in	Waterfowl, small mammals	Full sun to partial shade
Burreed (Sparganium americanum)	2, 3	Emergent	0-6	Waterfowl, small mammals	Full sun to partial shad
Cardinal Flower * (Lobelia cardinalis)	3	Perimeter	Periodic inundation	Attracts hummingbirds	Full sun to partial shade
Common Rush (Juncus spp.)	2, 3	Emergent	Up to 12 in.	Moderate; small mammals, waterfowl, songbirds	Full sun to partial shade
Common Three Square (Scipus pungens)	2	Emergent	Up to 6 in.	High; seeds, cover, waterfowl, songbirds	Fast colonizer; can tolerate periods of dryness; full sun; high metal removal

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Duckweed (Lemna sp.	1, 2	Submergent / Emergent	Yes	High; food for waterfowl and fish	May biomagnify metals beyond concentrations found in the water
Joe Pye Weed (Eupatorium purpureum)	2, 3	Emergent	Drier than other Joe-Pye Weeds; dry to moist areas; periodic inundation	Butterflies, songbirds, insects	Tolerates all light conditions
Lizard's Tail (Saururus cernus)	2	Emergent	Up to 1 ft.	Low; except for wood ducks	Rapid growth; shade-tolerant
Marsh Hibiscus (Hibiscus moscheutos)	2, 3	Emergent	Up to 3 in.	Low; nectar	Full sun; can tolerate periodic dryness
Pickerelweed (Pontederia cordata)	2, 3	Emergent	Up to 1 ft.	Moderate; ducks, nectar for butterflies	Full sun to partial shade
Pond Weed (Potamogeton pectinatus)	1	Submergent	Yes	Extremely high; waterfowl, marsh and shore birds	Removes heavy metals from the water
Rice Cutgrass (Leersia oryzoides)	2, 3	Emergent	Up to 3 in.	High; food and cover	Prefers full sun, although tolerant of shade; shoreline stabilization
Sedges (Carex spp.)	2, 3	Emergent	Up to 3 in.	High; waterfowl, songbirds	Wetland and upland species

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Softstem Bulrush (Scipus validus)	2, 3	Emergent	Up to 2 ft.	Moderate; good cover and food	Full sun; aggressive colonizer; high pollutant removal
Smartweed (Polygonum spp.)	2	Emergent	Up to 1 ft.	High; waterfowl, songbirds; seeds and cover	Fast colonizer; avoid weedy aliens, such as P. Perfoliatum
Spatterdock (Nuphar luteum)	2	Emergent	Up to 1.5 ft.	Moderate for food, but High for cover	Fast colonizer; tolerant of varying water levels
Switchgrass (Panicum virgatum)	2, 3, 4	Perimeter	Up to 3 in.	High; seeds, cover; waterfowl, songbirds	Tolerates wet/ dry conditions
Sweet Flag * (Acorus calamus)	2, 3	Perimeter	Up to 3 in.	Low; tolerant of dry periods	Tolerates acidic conditions; not a rapid colonizer
Waterweed (Elodea canadensis)	1	Submergent	Yes	Low	Good water oxygenator; high nutrient, copper, manganese and chromium removal
Wild celery (Valisneria americana)	1	Submergent	Yes	High; food for waterfowl; habitat for fish and invertebrates	Tolerant of murky water and high nutrient loads

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Wild Rice (Zizania aquatica)	2	Emergent	Up to 1 ft.	High; food, birds	Prefers full sun
Woolgrass (Scirpus cyperinus)	3, 4	Emergent	yes	High: waterfowl, small mammals	Fresh tidal and nontidal, swamps, forested wetlands, meadows, ditches

[1]Zone 1: -6 to -12 **OR** -18 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 to +36 inches; above detention storage zone
* Not a major colonizer, but adds color (Aggressive colonizers are shown in **bold** type)

Suitable Tree Species. The major shift in Stormwater Wetland design is to integrate trees and shrubs into the design, in tree islands, peninsulas, and fringe buffer areas. Deeper-rooted trees and shrubs that can extend to the Stormwater Wetland's local water table are important for creating a mixed wetland community. **Table SW-4** above presents some recommended tree and shrub species in the mid-Atlantic region for different inundation zones. A good planting strategy includes varying the size and age of the plant stock to promote a diverse structure. Using locally grown container or bare root stock is usually the most successful approach, if planting in the spring. Trees may be planted in clusters to share rooting space on compacted wetland side-slopes. Planting holes should be amended with compost (a 2:1 ratio of loose soil to compost) prior to planting.

Pre- and Post-Nursery Care. Plants should be kept in containers of water or moist coverings to protect their root systems and keep them moist when in transporting them to the planting location. As much as six to nine months of lead time may be needed to fill orders for wetland plant stock from aquatic plant nurseries (**Appendix F**).

4.2.11. Stormwater Wetlands (SW)

SW-5. Materials Specifications

Stormwater Wetlands are generally constructed with materials obtained on-site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and filter fabric for lining banks or berms.

Plant stock should be nursery grown, unless otherwise approved by the local regulatory authority, and should be healthy and vigorous native species free from defects, decay, disfiguring roots, sun-scald, injuries, abrasions, diseases, insects, pests, and all forms of infestations or objectionable disfigurements, as determined by the local regulatory authority.

4.2.11. Stormwater Wetlands (SW)

SW-6. Design Adaptations

SW-6.1. Karst Terrain

Even shallow pools in karst terrain can increase the risk of sinkhole formation and groundwater contamination. Designers should always conduct geotechnical investigations in karst terrain to assess this risk during the project planning stage. If Stormwater Wetlands are employed in karst terrain, the designer must:

- Employ an impermeable liner that meets the requirements outlined in **Table SW-6.**
- Maintain at least 3 feet of vertical separation from the underlying karst bedrock layer.
- Shallow, linear and multiple cell wetland configurations are preferred.
- Deeper basin configurations, such as the pond/wetland system have limited application in karst terrain.

Table SW-6. Required Groundwater Protection Liners for Ponds in Karst Terrain

Situation	Criteria
Not excavated to bedrock	24 inches of soil with a maximum hydraulic conductivity of 1×10^{-5} cm/sec
Excavated to or near bedrock	24 inches of clay[1] with maximum hydraulic conductivity of 1×10^{-6} cm/sec
Excavated to bedrock within wellhead protection area, in recharge are for domestic well or spring, or in known faulted or folded area	24 inches of clay[1] with maximum hydraulic conductivity of 1×10^{-7} cm/sec and a synthetic liner with a minimum thickness of 60 mil.

[1] Plasticity Index of Clay: Not less than 15% (ASTM D-423/424)
Liquid Limit of Clay: Not less than 30% (ASTM D-2216)
Clay Particles Passing: Not less than 30% (ASTM D-422)
Clay Compaction: 95% of standard proctor density (ASTM D-2216)

Source: WVDEP, 2006 and VA DCR, 1999

SW-6.2. Steep Terrain

Some adjustment can be made by terracing wetland cells in a linear manner as with Regenerative Stormwater Conveyance Systems (**Specification 4.2.7, Regenerative Stormwater Conveyance**) or by dividing the system into discrete cells to take advantage of relatively flat areas on a site.

SW-6.3. Cold Climate and Winter Performance

Wetland performance decreases when snowmelt runoff delivers high pollutant loads. Shallow Stormwater Wetlands can freeze in the winter, which allows runoff to flow over the ice layer and exit without treatment. Inlet and outlet structures close to the surface may also freeze, further diminishing wetland performance. Salt loadings are higher in cold climates due to winter road maintenance. High chloride inputs have a detrimental effect on native wetland vegetation and can shift the wetland plant composition to more salt-tolerant but less desirable species, such as cattails (Wright et al., 2006). Designers should choose salt-tolerant species when crafting their planting plans and consider specifying reduced salt applications in the CDA, when they actually have control of this. The following design adjustments are recommended for Stormwater Wetlands installed in higher elevations and colder climates.

- Treat larger runoff volumes in the spring by adopting seasonal operation of the permanent pool (see MSSC, 2005).
- Plant salt-tolerant wetland vegetation.
- Do not submerge inlet pipes and provide a minimum 1% pipe slope to discourage ice formation.
- Locate low flow orifices so they are located at least 6 inches below the typical ice layer.
- Angle trash racks to prevent ice formation.
- Over-size the riser and weir structures to avoid ice formation and freezing pipes.
- If road sanding is prevalent in the contributing drainage area, increase the forebay size to accommodate additional sediment loading.

SW-6.4. Linear Highway Sites

Under certain circumstances, linear wetland cells and regenerative conveyance systems may be suitable to treat runoff within open channels located in the highway right of way.

4.2.11. Stormwater Wetlands (SW)

SW-7. Construction & Installation

SW-7.1. Construction Sequence

The construction sequence for Stormwater Wetlands depends on site conditions, design complexity, and the size and configuration of the proposed facility. The following two-stage construction sequence is recommended for installing an on-line wetland facility and establishing vigorous plant cover.

Stage 1 Construction Sequence: Wetland Facility Construction.

Step 1: Stabilize Drainage Area. Stormwater Wetlands should only be constructed after the CDA to the wetland is completely stabilized. If the proposed wetland site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 2: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 3: Clear and Strip the project area to the desired sub-grade.

Step 4: Install Erosion and Sediment Controls prior to construction, including temporary dewatering devices, sediment basins, and stormwater diversion practices. All areas surrounding the wetland that are graded or denuded during construction of the wetland are to be planted with turf grass, native plant materials or other approved methods of soil stabilization. Grass sod is preferred over seed to reduce seed colonization of the wetland. During construction the wetland must be separated from the CDA so that no sediment flows into the wetland areas. In some cases, a phased or staged erosion and sediment control plan may be necessary to divert flow around the Stormwater Wetland area until installation and stabilization are complete.

Step 5: Excavate the Core Trench for the Embankment and Install the Spillway Pipe. Follow standard embankment construction procedures.

Step 6: Install the Riser or Outflow Structure and ensure that the top invert of the overflow weir is constructed level and at the proper design elevation (flashboard risers are strongly recommended by Hunt et al, 2007).

Step 7: Construct the Embankment and any Internal Berms in 8 to 12-inch lifts and compacted with appropriate equipment.

Step 8: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the wetland. This is normally done by "roughing up" the interim elevations with a skid loader or other similar equipment to achieve the desired topography across the wetland. Spot surveys should be made to ensure that the interim elevations are 3 to 6 inches below the final elevations for the wetland.

Step 9: Install Micro-Topographic Features and Soil Amendments within wetland area. Since most Stormwater Wetlands are excavated to deep sub-soils, they often lack the nutrients and organic matter needed to support vigorous growth of wetland plants. It is therefore essential to add sand, compost, topsoil or wetland mulch to all depth zones in the wetland. The importance of soil amendments in excavated wetlands cannot be over-emphasized; poor survival and future wetland coverage are likely if soil amendments are not added. The planting soil should be a high organic content loam or sandy loam, placed by mechanical methods, and spread by hand. Planting soil depth should be at least 4 inches for shallow wetlands. No machinery should be allowed to traverse over the planting soil during or after construction. Planting soil should be tamped as directed in the design specifications, but it should not be overly compacted. After the planting soil is placed, it should be saturated and allowed to settle for at least one week prior to installation of plant materials.

Step 10: Construct the Emergency Spillway in cut or structurally stabilized soils.

Step 11: Install Outlet Pipes, including the downstream rip-rap apron protection.

Step 12: Stabilize Exposed Soils with temporary (annual) seed mixtures appropriate for a wetland environment. All wetland features above the normal pool elevation should be temporarily stabilized. Avoid perennial and invasive seed mixes, such as fescues.

Stage 2 Construction Sequence: Establishing the Wetland Vegetation.

Step 13: Finalize the Wetland Landscaping Plan. At this stage the engineer, landscape architect, and wetland expert work jointly to refine the initial wetland landscaping plan after the Stormwater Wetland has been constructed. Several weeks of standing time is needed so that the designer can more precisely predict the following two things:

- Where the inundation zones are located in and around the wetland; and
- Whether the final grade and wetland microtopography will persist over time.

This allows the designer to select appropriate species and additional soil amendments, based on field confirmation of soils properties and the actual depths and inundation frequencies occurring within the wetland.

Step 14: Open Up the Wetland Connection. Once the final grades are attained, the pond and/or CDA connection should be opened to allow the wetland cell to fill up to the normal pool elevation. Inundation must occur in stages so that deep pool and high marsh plant materials can be placed effectively and safely. Wetland planting areas should be at least partially inundated during planting to promote plant survivability.

Step 15: Measure and Stake Planting Depths at the onset of the planting season. Depths in the wetland should be measured to the nearest inch to confirm the original planting depths of the planting zone. At this time, it may be necessary to modify the plan to reflect altered depths or a change in the availability of wetland plant stock. Surveyed planting zones should be marked on the as-built or design plan, and their locations should also be identified in the field, using stakes or flags.

Step 16: Propagate the Stormwater Wetland. Three techniques are used in combination to propagate the emergent community over the wetland bed:

1. Initial Planting of Container-Grown Wetland Plant Stock. The transplanting window extends from early April to mid-June. Planting after these dates is quite chancy, since emergent wetland plants need a full growing season to build the root reserves needed to get through the winter. If at all possible, the plants should be ordered at least 6 months in advance to ensure the availability and on-time delivery of desired species.
2. Broadcasting Wetland Seed Mixes. The higher wetland elevations should be established by broadcasting wetland seed mixes to establish diverse emergent wetlands. Seeding of switchgrass or wetland seed mixes as a ground cover is an option for all zones above 3 inches below the normal pool elevation. Hand broadcasting or hydroseeding can be used to spread seed, depending on the size of the wetland cell.
3. Allowing "Volunteer" Wetland Plants to Establish on Their Own. The remaining areas of the Stormwater Wetland will eventually (within 3 to 5 years) be colonized by volunteer species from upstream or the forest buffer.

Step 17: Install Goose Protection to Protect Newly Planted or Newly Growing Vegetation. This is particularly critical for newly established emergent and herbaceous plants, as predation by Canada geese can quickly decimate wetland vegetation. Goose protection can consist of netting, webbing, or string installed in a criss-cross pattern over the surface area of the wetland, above the level of the emergent plants.

Step 18: Plant the Wetland Fringe and Buffer Area. This zone generally extends from 1 to 3 feet above the normal pool elevation. Consequently, plants in this zone are infrequently inundated (5 to 10 times per year), and must be able to tolerate both wet and dry periods.

SW-7.2. Construction Inspection.

Construction inspections are critical to ensure that Stormwater Wetlands are properly constructed and established. Multiple site visits and inspections are recommended during the following stages of the wetland construction process:

- Pre-construction meeting
- Initial site preparation (including installation of project erosion and sediment controls)
- Excavation/grading (e.g., interim/final elevations)
- Wetland installation (e.g., microtopography, soil amendments and staking of planting zones)
- Planting phase (with an experienced landscape architect or wetland expert)
- Final inspection (develop a punch list for facility acceptance)

A construction phase inspection checklist for Stormwater Wetlands can be found in Appendix A.

SW-8. Maintenance Criteria

SW-8.1. Maintenance Agreements

Section C.b.5.ii(C) of the MS4 General Permit requires a maintenance agreement and plan between the property owner or operator and the local program authority (for municipal separate storm sewer systems). This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel. Stormwater Wetlands must be covered by a drainage easement to allow inspection and maintenance.

SW-8.2. First 2 Years Maintenance Operations

Successful establishment of Stormwater Wetland areas requires that the following tasks be undertaken in the first two years (CWP, 2004):

- **Initial Inspections.** During the first 6 months following construction, the site should be inspected at least twice after storm events that exceed 1/2 inch of rainfall.
- **Spot Reseeding.** Inspectors should look for bare or eroding areas in the CDA or around the wetland buffer, and make sure they are immediately stabilized with grass cover.
- **Watering.** Trees planted in the buffer and on wetland islands and peninsulas need watering during the first growing season. In general, consider watering every three days for the first month, and then weekly during the first growing season (April - October), depending on rainfall.
- **Reinforcement Plantings.** Regardless of the care taken during the initial planting of the wetland and buffer, it is probable that some areas will remain unvegetated and some species will not survive. Poor survival can result from many unforeseen factors, such as predation, poor quality plant stock, water level changes, and/or drought. Thus, it is advisable to budget for an additional round of reinforcement planting after one or two growing seasons. Construction contracts should include a care and replacement warranty extending at least two growing seasons after initial planting, to selectively replant portions of the wetland that fail to fill in or survive. If a minimum coverage of 50% is not achieved in the planted wetland zones after the second growing season, reinforcement planting will be required.

SW-8.3. Inspections and On-going Maintenance

Ideally, maintenance of Stormwater Wetlands should be driven by annual inspections that evaluate the condition and performance of the wetland. Based on inspection results, specific maintenance tasks will be triggered. An example maintenance inspection checklist for Stormwater Wetlands can be found in Appendix A.

Managing vegetation is an important ongoing maintenance task at every Stormwater Wetland and for each inundation zone. Following the design criteria above should result in a reduced need for regular mowing of the embankment and access roads. Vegetation within the wetland, however, will require some annual maintenance.

Designers should expect significant changes in wetland species composition to occur over time. Inspections should carefully track changes in wetland plant species distribution over time. Invasive plants should be dealt with as soon as they begin to colonize the wetland. As a general rule, control of undesirable invasive species (e.g., cattails and Phragmites) should commence when their coverage exceeds more than 15% of a wetland cell area. Although the application of herbicides is not recommended, some types (e.g., Glyphosate) have been used to control cattails with some success. Extended periods of dewatering may also work, since early manual removal provides only short-term relief from invasive species. While it is difficult to exclude invasive species completely from Stormwater Wetlands, their ability to take over the entire wetland can be reduced if the designer creates a wide range of depth zones and a complex internal structure within the wetland.

Thinning or harvesting of excess forest growth may be periodically needed to guide the forested wetland into a more mature state. Vegetation may need to be harvested periodically if the Stormwater Wetland becomes overgrown. Thinning or harvesting operations should be scheduled to occur approximately 5 and 10 years after the initial wetland construction. Removal of woody species on or near the embankment and maintenance access areas should be conducted every 2 years.

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Chapter 5. Stormwater Hotspots

What's in This Chapter

Section 5.1 provides a brief overview of the potential stormwater hotspot stipulations from Minimum Measure #5 – Controlling Runoff from New Development and Redevelopment – and provides a definition for hotspots.

Section 5.2 provides guidance on common stormwater hotspot generating areas and appropriate best management practice (BMP) design considerations.

Section 5.3 provides a checklist reviewers and designers can use to detail how stormwater runoff from hotspot sites is being managed.

Chapter 5. Stormwater Hotspots

5.1. Stormwater Hotspot Regulatory Requirements

This section provides a brief overview of the Stormwater Hotspot regulatory requirements of Minimum Measure #5 ("Controlling Runoff from New Development and Redevelopment"). Readers are encouraged to consult the MS4 General Permit and associated fact sheet to obtain more detailed information and specific standards.

Stormwater Hotspot Regulatory Requirements

Part II, Section C.b.5.a.ii of the MS4 General Permit outlines the Stormwater Hotspot regulatory requirements of Minimum Measure #5. This section requires the MS4 or permittee to meet the following water quality requirements:

i. A project that is a potential hotspot with reasonable potential for pollutant loading(s) must provide water quality treatment for associated pollutants (e.g., petroleum hydrocarbons at a vehicle fueling facility) before infiltration.

ii. A project that is a potential hotspot with reasonable potential for pollutant loading(s) that cannot implement adequate preventative or water quality treatment measures to ensure compliance with groundwater and/or surface water quality standards, must properly convey stormwater to a National Pollutant Discharge Elimination System (NPDES)-permitted wastewater treatment facility or via a licensed waste hauler to a permitted treatment and disposal facility.

Stormwater Hotspots are defined as commercial, industrial, institutional, municipal, or transport related operations that produce higher levels of stormwater pollutants, and/or present a higher potential risk for spills, leaks or illicit discharges.

Chapter 5. Stormwater Hotspots

Section 5.2. Guidance for Hotspot Land Uses

Table 5.1 presents a list of potential land uses or operations that may be designated as a stormwater hotspot. **Figure 5.1** illustrates several types of stormwater hotspots. Pollution prevention profile sheets for stormwater hotspot operations are found in Novotney and Winer (2008). At each hotspot, the drainage area that contributes higher levels of stormwater pollutants (or hotspot generating areas) may only include a portion of the site (e.g., the vehicle fueling area) while other "clean" non-hotspot generating areas (such as rooftops or travelways that don't "mix" with hotspot generating area runoff) can be treated as a "non-hotspot" area. As such, these requirements only apply to the hotspot generating area on a site, and the non-hotspot generating areas can be diverted away to another runoff reduction practice.

Communities should carefully review development proposals to determine if current or proposed future operations on all or part of the site should be designated as a stormwater hotspot. As recommended in Table 5.1, Infiltration BMPs should be restricted at some potential hotspots and prohibited at others. This largely depends on the relative risk that current or future operations and site activities will lead to harmful spills, leaks, and/or the generation of polluted runoff. At some site, the risk may be relatively low (e.g., a convenience stores, fast food restaurants, car dealerships), and restricted Infiltration can apply. Sites with higher risks (e.g., vehicle maintenance facilities, public works yards) should avoid any type of Infiltration, including unlined practices with an underdrain or infiltration sump (CSN, 2011). The local program may choose to further refine the list in Table 5.1 and/or determine hotspot categories where restricted or prohibited Infiltration may apply.

The designer can best work with the MS4 General Permit requirements by clearly defining hotspot generating areas and selecting appropriate BMPs for the generating areas and non-hotspot generating areas. For instance, the hotspot generating area could be treated by a perimeter sand filter or proprietary oil/water separator device, while the non-hotspot generating areas may use Bioretention, Permeable Pavement, or Swales.

In addition, the site designer should work with the local program authority to balance the need to treat hotspot generating area runoff with an appropriate BMP with the overall site performance standard to achieve runoff volume reduction for 1-inch of rainfall. In many cases, hotspot generating area BMPs (such as sand filters) do not achieve runoff reduction benefits, so the local program must either "waive" the hotspot generating area from the 1-inch requirement (as long as an appropriate BMP is used), overcompensate for runoff reduction on other parts of the site, or use the off-site mitigation or payment-in-lieu options outlined in the general permit.

Finally, a multi-sector stormwater general permit may be required for industrial facilities to minimize the operation's impacts to stormwater (See **Chapter 2, Table 2.2**). Operators should confer with West Virginia Department of Environmental Protection (WVDEP) NPDES staff on the applicability of the multi-sector general permit or other industrial stormwater permits for a particular application.

http://www.dep.wv.gov/WWE/Programs/stormwater/multisector/Pages/home.aspx

Table 5.1: Potential Stormwater Hotspot and Site Design Responses (CSN, 2009)

Potential Stormwater Hotspot Operation	Stormwater Pollution Prevention Plan (SWPPP) Required?	Restricted Infiltration for Hotspot Generating Area[1]	Prohibited Infiltration for Hotspot Generating Area[1]
Facilities w/NPDES Industrial permits (multi-sector general permit)	Yes	+	+
Public works yard	Yes		•
Auto and metal recyclers/scrap yards	Yes		•
Petroleum storage facilities	Yes		•
Highway maintenance facilities	Yes		•
Wastewater, solid waste, composting facilities	Yes		•
Industrial machinery and equipment	Yes	•	
Truck and trailer areas or maintenance facilities	Yes	•	
Aircraft maintenance areas	Yes		•
Fleet storage areas	Yes		•
Parking lots (40 or more parking spaces)[2]	No	•	
Gas stations	No		•
Highways (2500 ADT)	No	•	

Potential Stormwater Hotspot Operation	Stormwater Pollution Prevention Plan (SWPPP) Required?	Restricted Infiltration for Hotspot Generating Area[1]	Prohibited Infiltration for Hotspot Generating Area[1]
Construction business (paving, heavy equipment storage and maintenance)	No	•	
Retail/wholesale vehicle/ equipment dealers	No	•	
Convenience stores/fast food restaurants	No	•	
Vehicle maintenance facilities	No		•
Car washes (unless discharged to sanitary sewer)	No		•
Nurseries and garden centers	No	•	
Golf courses	No	•	

Note: For a full list of potential stormwater hotspots, please consult Wright et al. (2005)

Key: + depends on facility • Yes
Shaded Area Facilities or operations not technically required to have NPDES permits, but can be designated as potential stormwater hotspots by the local review authority, as part of their local stormwater ordinance
[1] See below for descriptions of restricted and prohibited infiltration.
[2] The local program may want to distinguish "dirty" parking lots with a higher potential for the deposition of oil/grease, solids, grit, trash, and other pollutants from parking lots with lower potential to accumulate these pollutants.

Figure 5.1: Common Stormwater Hotspot Operations

Vehicle Maintenance Facilities

Restaurant Storage Containers

Nurseries and Garden Center

Gas Station

Public Works Yard

Dumpster Management

If a site is designated as a potential hotspot, a range of stormwater treatment and pollution prevention practices can be applied to prevent contamination of surface or groundwater. Depending on the severity of the hotspot, one or more of the following management strategies identified in Table 5.1 and defined below may be required by the local review authority.

1. Stormwater Pollution Prevention Plan (SWPPP). This plan is required as part of an industrial or municipal stormwater permit, and outlines pollution prevention and treatment practices that will be implemented to minimize polluted discharges from the site. Other facilities or operations are not technically required to have NPDES permits, but can be designated as potential stormwater hotspots by the local review authority, as part of its stormwater ordinance (these are shown in the shaded areas of Table 6.1). It is recommended that these facilities include an addendum to their stormwater plan that details the pollution prevention practices and employee training measures that will be used to reduce contact of pollutants with rainfall or snowmelt.
2. Restricted Infiltration. A minimum of 50% of the total Target Treatment Volume (Tv) must be treated by a Filtration practice, "closed" Bioretention (contains a liner on the bottom), or proprietary device designed for the pollutants of concern prior to any infiltration. For small hotspot generating areas where the primary concern is spill containment, the pre-treatment can consist of a lined containment area sized for a typical tanker truck (5,500 to 9,000 gallons), or the expected volume of spills at the site. Portions of the site that are not associated with the hotspot generating area should be diverted away and treated by an acceptable stormwater practice.
3. Infiltration Prohibition. If a site is classified as a potentially severe hotspot, the risk of groundwater contamination is so great that infiltration of stormwater is prohibited. In these cases, an alternative stormwater practice, such as perimeter sand filters or proprietary devices designed for the pollutants of concern at the facility must be used to treat runoff from the hotspot generating area.

It is important to note that the MS4 General Permit speaks to potential hotspot generating areas that intend to use Infiltration as a stormwater BMP. This would include any practice that has an underdrain with an infiltration sump (stone layer below the underdrain pipe). In many cases, the designer may opt to use a stormwater BMP that is not designed to infiltrate water into the ground and/or does not have an infiltration sump. This is an acceptable approach. The most important thing is to select a practice that addresses the pollutants of concern from the hotspot generating area. For instance, a vehicle maintenance area where the pollutants of concern are hydrocarbons and metals may select a sand filter or proprietary device designed to treat for these pollutants. See Chapter 3 (Tables 3.5 and 3.7) for further guidance on BMP selection. In these cases, the designer should confer with the local program authority on how to integrate these BMP choices with the 1" runoff reduction performance standard, as noted above.

Chapter 5. Stormwater Hotspots

5.3 Hotspot Plan Review Checklist

Reviewers and designers can use the Stormwater Hotspot Cover Sheet and Stormwater Hotspot Checklist to document how the stormwater runoff from the hotspot is being managed. These two documents should be completed by the operator as part of the site design plan submittal.

Stormwater Hotspot Cover Sheet

Project Name:____

Applicant Name: ____

Date:____

Please indicate the appropriate hotspot operations for your project (check all that apply). If none apply check N/A.

Stormwater Hotspot Operations:

___ Vehicle Maintenance and Repair
___ Vehicle/Truck/Aircraft Fueling
___ Vehicle/Truck/Machinery Washing
___ Vehicle/Fleet/Construction Equipment Storage Area
___ Petroleum Storage
___ Auto/Metal Scrap/Recyling
___ Solid Waste/Composting
___ Aircraft Maintenance
___ Grease Traps/Grease Storage
___ Loading and Unloading
___ Outdoor or Bulk Material Storage
___ Storage/Application of Fertilizers/Pesticides

___ Other: ____
___ N/A

Other Stormwater Permits/Plans Required For the Site:

___ Multi-Sector General Permit. Permit #:
___ Other Industrial Stormwater Permit. Permit #:
___ Storm Water Pollution Prevention Plan (SWPPP) Completed. Submit with site plan.

If "N/A" is checked, please include this sheet only with plan submittal.

If a multi-sector general permit, other industrial stormwater permit, or SWPPP is not required for the site, please complete and submit the attached Stormwater Hotspot Checklist with the site plan.

___ Stormwater Hotspot Checklist attached

Stormwater Hotspot Checklist

Instructions: Complete the following site information:

	Requirement	Description
Site Description	List the type of facility and facility address	
Site Operations	Describe the operations to be conducted on-site.	
Receiving Waters	Name(s) of the receiving water(s). If drains to a municipal storm sewer system, include ultimate receiving waters.	
Site Materials	Significant materials to be stored on site (specify indoor or outdoor storage)	
Stormwater Management Practices	List the stormwater management practices being used to treat runoff from the site. Where appropriate, include description of design modifications appropriate for treatment of hotspot runoff	
Spill Prevention and Response	Describe methods to prevent spills along with clean-up and notification procedures.	
Employee Education Program	Description of employee orientation and education program.	

Instructions: Fill in the appropriate page number(s) from the site plans where the following site elements are clearly indicated.

Site elements	Site Plan Sheet Number(s)	Check if N/A	Approved (for official use only)
Material loading and access areas			
Material storage and handling areas			
Cleaning and maintenance areas			
Vehicle or machinery storage areas			
Vehicle or machinery maintenance/service areas			
Treatment or disposal areas for significant materials			
Hazardous waste storage areas			
Areas of outdoor manufacturing			
Stormwater management calculations			
Drainage area outline for each storm water inlet or structure			
Stormwater management practices			
Stormwater management maintenance inspection agreements			
Spill Prevention and Response Kits			
Facility inspection agreements for inspections of areas where potential spills of significant materials or industrial activities can impact stormwater			

For official use only:		
Date of Submission: ______________ Date Received: ______________	Reviewed by: ________________ Reviewed on: ________________	Plan Accepted:Y / N

REFERENCES

Wright, T., C. Swann, K. Cappiella, T. Schueler. 2005. Unified Subwatershed and Site Reconnaissance: A User's Manual-Version 2.0. Manual 11 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

Chesapeake Stormwater Network (CSN). 2011. Stormwater Design for High Intensity Redevelopment Projects in the Chesapeake Bay Watershed. Version 3.0. CSN Technical Bulletin No. 5. Catonsville, MD

Chesapeake Stormwater Network (CSN). 2009. Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed. Version 2.0. CSN Technical Bulletin No. 1. Catonsville, MD.

Novotney, M. and R. Winer. 2008. Municipal Pollution Prevention/Good Housekeeping Practices – Version 1.0. Manual 9 in the Urban Subwatershed restoration Manual Series. Center for Watershed Protection, Inc., Ellicott City, MD.

6.1: Permeable Pavement (Level 1) and Sheet Flow to Conservation Area

The site plan and drainage area map for Example 1 is shown in **Figure 6.1.1**. The site is a small commercial facility that hosts receptions and social events and therefore has a large number of parking spaces. The site consists of 5.6 acres of open space, managed turf, and impervious cover. Table 6.1.1 provides the Site Data.

Table 6.1.1 Site Data

Land Cover Type	Area (acres)
Forest/Preserved Open Space	1.1
Managed Turf	2.3
Impervious Cover	2.2
Total	5.6

The site is readily divided into six drainage areas:

- Areas A through E consists of the improved portions of the site: parking areas, sidewalks, landscaping, and disturbed areas that represent the limits of grading and earthwork around the improvements. Area E consists of the building,
- Area F consists of the perimeter areas of the site between the limits of disturbance and the site boundary. These areas are protected from impacts from construction equipment.

Table 6.1.2 provides a breakdown of the six drainage areas:

Table 6.1.2 Site and Drainage Area Land Cover Data

Drainage Area Number	Land Cover Type	Land Cover (Acres)	Drainage Area Size (acres)
DA A	Forest/Open Space		0.69
	Managed Turf		
	Impervious Cover	0.69	

Drainage Area Number	Land Cover Type	Land Cover (Acres)	Drainage Area Size (acres)
DA B	Forest/Open Space		0.66
	Managed Turf	0.14	
	Impervious Cover	0.52	
DA C	Forest/Open Space		0.30
	Managed Turf		
	Impervious Cover	0.30	
DA D	Forest/Open Space		0.43
	Managed Turf	0.02	
	Impervious Cover	0.41	
DA E	Forest/Open Space		0.28
	Managed Turf		
	Impervious Cover	0.28	
DA F[1]	Forest/Open Space	1.10	3.20
	Managed Turf	2.10	
	Impervious Cover		
Total		5.56	5.56

[1] Drainage Area F represents the perimeter undisturbed areas of the site. This area would typically be broken into sub-areas based on the drainage patterns, and could be managed (if needed) along with BMPs in the adjacent drainage areas (A through E).

STEP 1 Site Assessment/Narrative:

Refer to **Chapter 2.3**: General Compliance Procedure for New Development and Redevelopment Projects; and Refer to Chapter 4.1: "Self-Crediting" Better Site Design Practices.

The reader should note that the perimeter undisturbed area (DA F) is considered to be self crediting since leaving it as undisturbed will generate less runoff. Additional self-crediting can be achieved if portions of this perimeter area can be designated as open space. This will require some form of easement or protective covenant to prevent the typical turf management practices of fertilization, mowing, etc.

This example will address the parking lot designated on Figure 6.1.1 as Drainage Area A.

STEP 2: Evaluate BMP Options

Reference to **Chapter 3.3 BMP Selection.**

Drainage Area A consists entirely of impervious cover.

Drainage Area A Characteristics/Feasibility (**Table 3.6** of Chapter 3)

- Soil type: Soils consist of HSG B & C soils, and are mapped as HSG B soil complex. The parking area is in slight cut at the southern end and transitions to slight fill in the northern end. The bottom of the permeable pavement section across the entire parking lot is in cut.
- Water Table: Soil survey and field verification indicates the seasonal water table to be a depth greater than 5 feet below existing grade.
- Bedrock: Soil survey and field verification indicates the bedrock to be a depth greater than 5 feet below existing grade.
- Hydraulic Head: Based on the existing and proposed grades, there appears to be at least three to four feet of available hydraulic head to discharge under drains and the drainage system.
- Slopes: mild slopes
- Drainage Area size: Drainage area A = 29,940 ft^2
- Available space: space is available under the pavement and at the perimeter of the parking area

Select Level 1 Permeable Pavement discharging to a Conservation Area with partial A/B and C/D soils (located along the northwest edge of the parking lot.

STEP 3: Determine BMP Drainage Areas and Treatment Volume (Tv)

Drainage Area Descriptions: Drainage Area A consists entirely of a parking lot (impervious cover) that will be managed using permeable pavement in seven distinct drainage sub-areas itemized in **Table 6.1.3,** and shown in **Figure 6.1.2.,** labeled as sub-areas 1 through 7.

- The drainage areas consist of the paved areas only as the grading allows the adjacent pervious areas to drain away from the pavement. (**This is a critical design element of permeable pavement – any contributing drainage area to the permeable pavement should be 100% impervious.**)

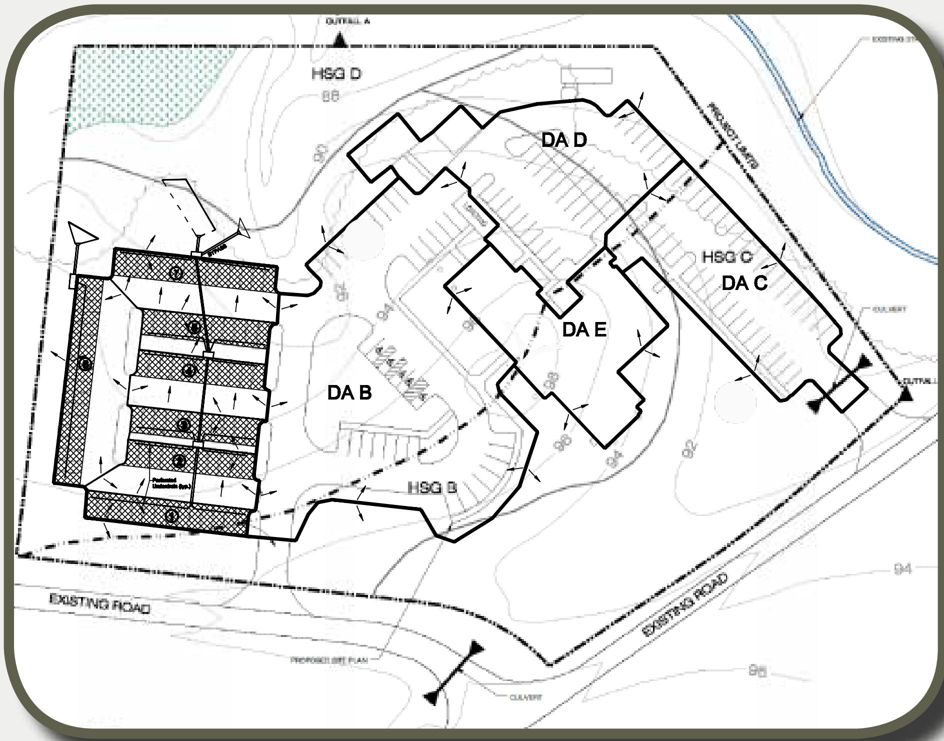

Figure 6.1.1. Drainage Areas

Treatment Volume for Drainage Area A from the Site Data Tab in the West Virginia Compliance Spreadsheet or the following equation:

Equation 3.1 (Chapter 3):

$$Tv = \frac{P \times (Rv_I \times \%I + Rv_T \times \%T + Rv_F \times \%F) \times SA}{12}$$

Where:

- Tv = Target Treatment Volume, in acre-feet (ac.-ft.)
- P = Depth of target rainfall event = 1"
- Rv_I = Volumetric Runoff Coefficient for impervious cover (unit-less)[1] = 0.95
- %I = Percent of site in impervious cover (fraction) = 1
- Rv_T = Volumetric Runoff Coefficient, turf or disturbed soils (unit-less)[1] = 0.2
- %T = Percent of site in turf cover (fraction) = 0
- Rv_F = Volumetric Runoff Coefficient for forest cover (unit-less)[1] = 0.03
- %F = Percent of site in forest cover (fraction) = 0
- SA = Total site area = 29,940 ft^2 = 0.69 acres

[1] Refer to Table 3.10

Equation 3.1 reduces to:

$$Tv = \frac{1" \times (0.95 \times 1) \times 0.69}{12} = 0.0546\ ac.ft = 2{,}379\ ft^3$$

Table 6.1.3. Drainage Area A Sub-Area Tabulation

Drainage Sub-Area Label	Area of Permeable Pavement (A_p) (ft²)	Contributing Impervious Drainage Area (A_I) (ft²)	Total Sub-Area (ft²)	Design Treatment Volume (ft³)
1	2,520	0	2,520	200
2	2,000	2,640	4,640	367
3	2,600[1]	0	2,600	206
4	2,000	2,640	4,640	367
5	3,200[1]	0	3,200	253
6	3,240	3,600	6,840	542
7	2,520	3,000	5,500	435
		Drainage Area A Total	29,940	2,370[2]

[1]The parking islands on the upstream side of sub-areas 3 and 5 are proposed to be impervious (decorative pavers or similar) and can be eliminated in favor of a continuous section of permeable pavement with wheel-stops to facilitate pavement construction.
[2]Difference of 9 ft³ from calculated value from rounding.

STEP 4: BMP Sizing and Design

The sub-areas are very similar in terms of size and the selected strategy of utilizing permeable pavement. The two design variants are the sections that have no external contributing area. The design of the permeable pavement section for sub-areas 1 and 6 will be provided here. The remaining sections follow a similar design.

Design Steps:

Permeable Pavement: Determine the depth of the stone reservoir – Sub-Area 1. Equation 4.1 from **Chapter 4.2.4** provides the required depth of the stone reservoir to manage the runoff volume form the one-inch rainfall. This also includes the adjacent contributing drainage area.

Equation 4.1

$$d_{stone} = \frac{(P \times A_I \times Rv_I) + (P \times A_P)}{\eta_r \times A_P}$$

d_{stone} = Depth of the stone reservoir layer (ft)
P = Rainfall depth (1") for the design Treatment Volume = 0.083
A_I = Contributing impervious drainage area (ft^2)
Rv_I = Volumetric Runoff Coefficient for impervious cover = 0.95
A_P = Area of permeable pavement (ft^2)
η_r = porosity of reservoir layer (0.4)

$$d_{stone(sub-area\ 1)} = \frac{(0.083 \times 0 \times 0.95) + (0.083 \times 2520)}{0.4 \times 2520} = 0.21\ ft; use\ 0.5\ ft.$$

NOTE: *The minimum stone depth based on the design Treatment Volume is defined by Equation 4.1. However, the minimum stone depth for permeable pavement will often be dictated by the pavement section design as a function of the anticipated traffic loading, pavement type (asphalt, concrete, or interlocking pavers), and the strength of the sub-grade soils. Clays and highly expansive soils may require additional design of the sub-grade – either the use of an extra depth of stone, or a geo-grid designed for the specific conditions.*

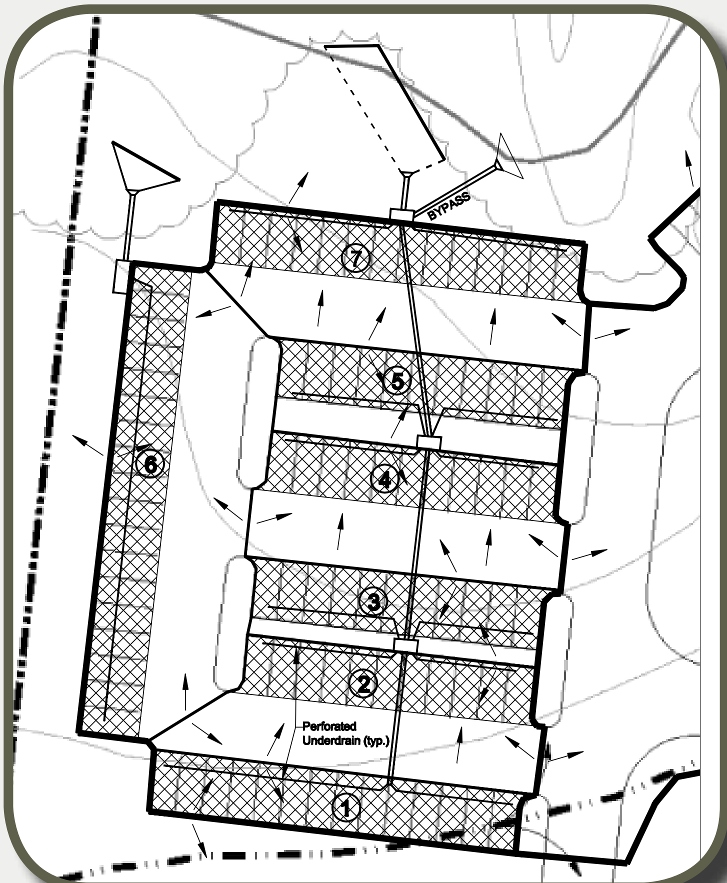

Figure 6.1.2. Drainage Area A with Sub-Areas 1 thru 7 Delineated

In the absence of a minimum design factor based on the structural design of the pavement, the reservoir depth should be a minimum of 6 inches above the underdrain or choker layer. The annual runoff reduction volume credit is limited to the credit applied to the design treatment volume based on contributing drainage area, regardless of the reservoir depth. Additional volume reduction credit is not provided for oversized reservoir storage.

Permeable Pavement: Determine the depth of the stone reservoir – Sub-Area 6. Sub-area 6 is larger, and therefore has a larger d_{stone}, however the recommended minimum of 6 inches of stone above the underdrain governs.

Equaiton PP-1

$$d_{stone} = \frac{(P \times A_I \times Rv_I) + (P \times A_P)}{\eta_r \times A_P}$$

$$d_{stone(sub-area\ 2)} = \frac{(0.083 \times 3{,}600 \times 0.95) + (0.083 \times 3{,}240)}{0.4 \times 3{,}240} = 0.43\ ft; use\ 0.5\ ft.$$

The recommended minimum of six inches of reservoir depth above the underdrain is adequate to achieve the 45% (0.45 watershed-inches) runoff reduction credit. The Level 1 permeable pavement design section for sub-areas 1 and 6 are shown in **Figure 6.1.3**.

Discharge from the permeable pavement underdrains is directed to Conservation Area by way of two outfalls: one serving sub-areas 1, 2, 3, 4, 5, and 7; and the second serving sub-area 6. (**Figure 6.1.2**)

Sheet Flow to Conservation Areas: The conservation area designated for the discharge from the permeable pavement underdrains and overflow inlets is a partially wooded buffer area that already has a very flat slope, and adequate vegetation. Inspections may note the need for spot enhancements to help avoid channeling, however, the primary design element will be the construction of level spreaders. Several different designs are illustrated in BMP **Specification 4.2.1**.

Conservation Areas for Sub-Areas 1, 2, 3, 4, 5, and 7 (Outfall 1):

1. Determine the peak discharge for the design off the Level Spreader with by-pass structure:

   - Determine peak Q_{10} and peak Q_{Tv} for combined sub areas 1, 2, 3, 4 and 5:
     - Q_{10} : Rational Method Q = CIA; C = 0.8 (WVDOH Drainage Manual, Table 4-4); I_{10}= 6.1"/hr (WVDOH Drainage Manual Chart 4-2, Appalachian Plateau; Tc = 5 min);

       Q_{10}= 0.8*6.1*0.531 = 2.6 cfs;

     - Q_{TV}: Two methods are referenced – NRCS method in Appendix F; and Rational Method using 1"/hr in sizing the level spreader rigid lip in Design Specification 4.2.1 Vegetated Filter Strips and Conservation Areas (use the larger, more conservative value):

       NRCS Method: Q_{TV} = 0.6 cfs

       Rational Method: Q_{TV} = 0.8*1*0.531 = 0.4 cfs

   - Design by-pass structure to divert 0.6 cfs to the level spreader; and safely bypass 2.6 cfs to a stable outfall conveyance.

2. Design Level Spreader and designate Conservation Area minimum width:
   - From Specification 4.2.1, 40 feet of level spreader length is to be provided for every 1 cfs of inflow (with a total maximum length of 130 ft.) when the spreader discharges to a Conservation Area consisting of forested or reforested buffer. This outfall is equipped with a by-pass structure so the level spreader is sized for 0.6 cfs:
     - Minimum length of level spreader rigid lip = 0.6 cfs*40 l.f./cfs = 24 ft.
     - In order achieve maximum credit, a rigid lip of 60 l.f. is provided since the receiving conservation area is sufficient to accept a wider sheet flow.

   - The maximum dimensions of the conservation area should be verified in the field based on the topography and vegetation. Field verification indicates that the conservation area adjacent to the level spreader serving Outfall 1 extends 140 feet from the level spreader.

Conservation Area for Sub-Areas 6 (Outfall 2):

1. Determine the peak discharge for the design off the Level Spreader with by-pass structure:
   - Determine peak Q_{10} and peak Q_{Tv} for sub-area 6:
     - Q_{10} : Rational Method Q = CIA; C = 0.8 (WVDOH Drainage Manual, Table 4-4); I_{10}= 6.1"/hr (WVDOH Drainage Manual Chart 4-2, Appalachian Plateau; Tc = 5 min);

       Q_{10}= 0.8*6.1*0.531 = 0.8 cfs;

     - Q_{TV}: Two methods are referenced – NRCS method in Appendix F; and Rational Method using 1"/hr in sizing the level spreader rigid lip in Design Specification 4.2.1 Vegetated Filter Strips and Conservation Areas.

       NRCS Method: Q_{TV} = 0.2 cfs
       Rational Method: Q_{TV} = 0.8*1*0.531 = 0.1 cfs

   - There is no bypass structure for the outfall from sub-area 6.

2. Design Level Spreader and designate Conservation Area minimum width:
   - From Specification 4.2.1, 40 feet of level spreader length is to be provided for every 1 cfs of inflow (with a total maximum length of 130 ft.) when the spreader discharges to a Conservation Area consisting of forested or reforested buffer. This outfall is <u>not</u> equipped with a by-pass structure, so the level spreader is sized for Q_{10} = 0.8 cfs:
     - Minimum length of level spreader rigid lip = 0.8 cfs*40 l.f./cfs = 32 ft.
     - In order achieve maximum credit, a rigid lip of 60 l.f. is provided since the receiving conservation area is sufficient to accept a wider sheet flow.
   - The maximum dimensions of the conservation area should be verified in the field based on the topography and vegetation. Field verification indicates that the conservation area adjacent to the level spreader serving Outfall 2 extends 70 feet from the level spreader.
   - For purposes of measuring the runoff reduction credit, the first 40 feet of conservation area is in Hydrologic Group B soils, and the remaining 30 feet is in Hydrologic Group C soils.

STEP 5: Verify Compliance

Permeable Pavement:

Similar sizing calculations for the remainder of the sub-areas yield similarly shallow permeable pavement sections. The Level 1 Permeable Pavement design provides 45% volume reduction (or 0.45 watershed inches). The typical Level 1 cross section is shown in **Figure 6.1.3** and the cross section through Drainage Area 1 is shown in Figure 6.1.4.

Compliance as computed with the West Virginia Compliance Spreadsheet Drainage Area tab, or the following calculation for the entire drainage area (including all 7 sub-areas) can be summarized as follows:

Total remaining Treatment Volume (Tv) = 2,370 ft^3 – (2,370 ft^3 x 0.45) = 1,304 ft^3
Remaining from Outfall 1: 1,006 ft^3
Remaining from Outfall 2: 298 ft^3

Conservation Areas:

Outfall 1: Sheet flow to 60 ft. x 140 ft. Conservation Area in C/D soils provides a volume reduction credit of 4 ft^3 per 100 ft^2 of conservation area.

The credit derived from the Outfall 1 Conservation Area = (60 ft * 140 ft)*(4 ft^3/100ft^2) = 336 ft^3
Remaining Treatment Volume (Tv) at Outfall 1 = 1,006 ft^3 – 336 ft^3 = 670 ft^3

Outfall 2: Sheet flow to 60 ft x 40 ft. Conservation Area in A/B soils provides a credit of 9 ft^3 per 100 ft^2 of conservation area. Sheet flow to remaining 60 ft. x 90 ft. Conservation Area in C/D soils provides a volume reduction credit of 4 ft^3 per 100ft^2 of conservation area.
The credit derived from the Outfall 2 Conservation Area:
(60ft*40ft)*(9ft^3/100ft^2)+(60ft*90ft)*(4ft^3/100ft^2) = 432 ft^3
Remaining Treatment Volume (Tv) at Outfall 2 = 298 ft^3 – 432 ft^3 = 0 ft^3

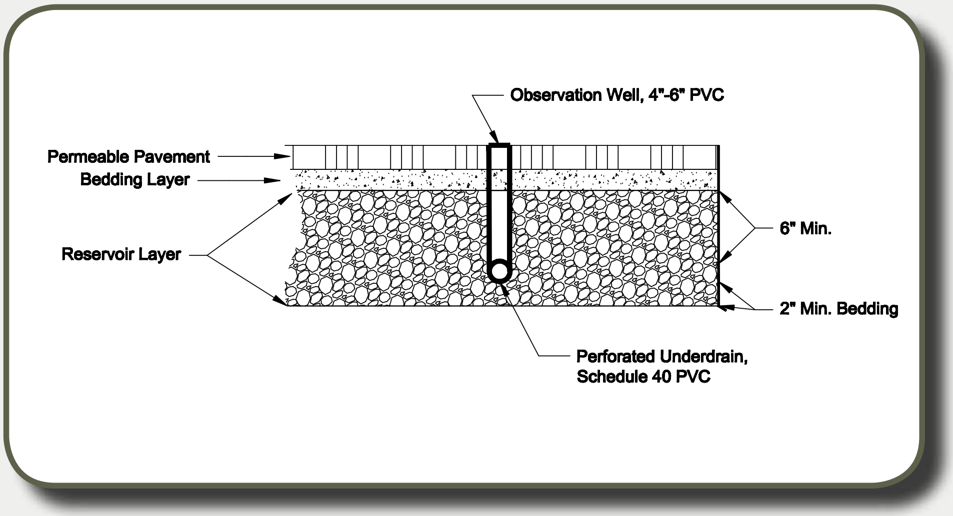

Figure 6.1.3. Typical Level 1 Permeable Pavement Section Sub-Areas 1 through 6

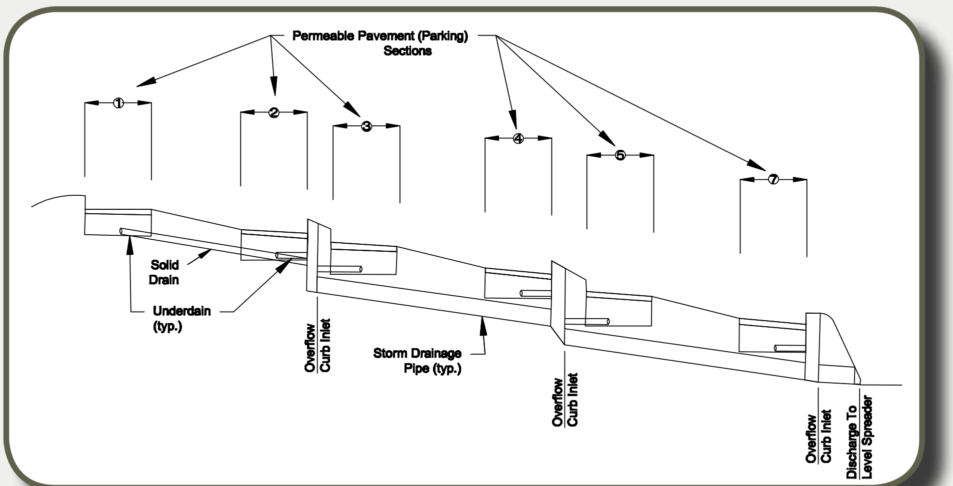

Figure 6.1.4. Cross Section of Sub-Areas 1 through 5 and 7

Overall Compliance Drainage Area 1:

The overall Runoff Reduction BMP design for Drainage Area 1 is 670 ft^3 short of the target design Treatment Volume. Specifically, the shortfall in treatment occurs in Outfall 1, draining sub-areas 1, 2, 3, 4, 5, and 7. The 134 ft^3 of additional volume managed in the Conservation Area of Outfall 2 cannot be credited toward reducing this deficit. Therefore, the shortage must either be managed through a fee-in lieu payment if available through the local plan approving authority, or the designer can evaluate other BMP options.

Since there is no space for additional BMPs downstream of the conservation areas, the designer should evaluate providing Level 1 Permeable Pavement – Refer to Example 6.2).

Example 6.2 provides the computations for sizing the infiltration sump.

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6.2 Design Example 2: Permeable Pavement (Level 2-Infiltration Sump)

This Example will apply the Level 2 Infiltration Sump design to Drainage Area A in an effort to manage the 670 ft^3 deficit computed in Example 6.1. The infiltration rates of the existing soils under the proposed permeable pavement must be verified in order to assess the applicability of an infiltration or infiltration sump design, and establish the depth of the stone reservoir or sump.

A **Level 2 Infiltration** design provides a **100%** (or one watershed-inch) runoff reduction credit for the volume of runoff above the filter layer and existing soils.

A **Level 2 Infiltration Sump** design provides a **45%** (or 0.45 watershed-inches) runoff reduction credit for the volume of the runoff above the underdrain, and a **100%** runoff reduction credit for the volume of runoff in the infiltration sump (below the underdrain and above the filter layer). However, the combined volume reduction credit of the two storage volumes cannot exceed 100% (or one watershed-inch) for the contributing drainage area.

STEP 1 Site Assessment/Narrative:

Refer to **Chapter 2.3:** General Compliance Procedure for New Development and Redevelopment Projects; and **Chapter 4.1**: "Self-Crediting" Better Site Design Practices

STEP 2: Evaluate BMP Options

Reference to **Chapter 3.3 BMP Selection.**

Site Characteristics/Feasibility (Table 3.6)

- Soils: The parking area is in a B soil complex. Following the infiltration testing criteria of **Appendix E,** the soils in this area have a verified infiltration rate of 0.5"/hr or greater (0.5"/hr will be used as the design value for the field verified infiltration rate). The area is in cut at the southern end (sub-area 1) and transitions to slight fill in the northern end (sub-area 7). The bottom of the permeable pavement section across the entire parking lot is in cut.
- The remaining site characteristics are repeated from **Example 6.1**.

Select Level 2 Permeable Pavement Infiltration Sump Design with infiltration rate (i) equal to 0.5"/hr.

STEP 3: Determine BMP Drainage Areas and Treatment Volume (Tv)

Drainage Area Descriptions:

The sub-areas and corresponding Treatment Volume for Drainage Area A are as noted in Table 6.1.3.

STEP 4: BMP Sizing and Design

The stone reservoir depth for sub-area 1 was determined in Example 7.1 to be 0.21 ft., and the stone reservoir depth for sub-area 6 to be 0.43 ft., with the minimum recommended depth for both areas set at 0.5 ft.

The maximum depth of the Infiltration Sump for all of the sub-areas of Drainage-Area 1 is determined using Equation 4.2 from **Chapter 4.2.4**:

Equation PP-2

$$d_{IS} = \frac{{}^{1}\!/_{2}\, i \times t_d}{12}$$

Where:

d_{IS} = Depth of the stone infiltration sump (ft)

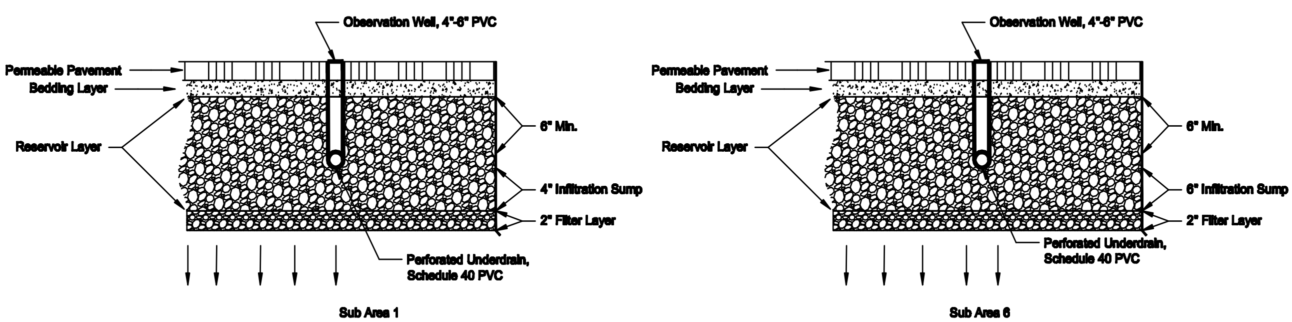
i = field-verified infiltration rate for the sub-grade soils = 0.5 "/hr.

t_d = design drain time of sump = 48 hours

$$d_{IS} = \frac{{}^{1}\!/_{2}\,(0.5) \times 48}{12} = 1.0\ ft.$$

Equation 4.3 (depth of stone reservoir above the infiltration sump, d_{res}) is not needed since the maximum depth of the infiltration sump (d_{IS} = 1.0 ft) exceeds the required stone reservoir depth for sub-area 1 (0.21 ft) and sub-area 6 (0.43 ft). Therefore, setting the depth of the infiltration sump equal to or greater than the stone reservoir depth will achieve a 100% runoff reduction credit for the contributing drainage area(s). An underdrain with the minimum recommended cover of 6 inches of stone and a 0.21 ft and 0.43 ft stone sump in sub-areas 1 and 6 respectively will therefore achieve a 100% volume treatment credit and provide for an underdrained system.

The Level 2 permeable pavement infiltration sump design section for sub-areas 1 and 6 are shown in **Figure 6.2.1.** The structural design of the pavement may require additional depth of stone or a geotextile. The Sheet Flow to conservation area is not needed for Drainage Area 1 as full compliance is achieved with the permeable pavement design.



Sub-Area 1 *Sub-Area 6*

Figure 6.2.1 Typical Level 2 Permeable Pavement Infiltration Sump Section

6.3. Design Example 3: Bioretention

This example continues with the site plan introduced in Example 6.1 and addresses the treatment volume generated in Drainage Area B as shown in Figure 6.3.1.

STEP 1 Site Assessment/Narrative:

Refer to Chapter 2.3: General Compliance Procedure for New Development and Redevelopment Projects; and Chapter 4.1: "Self-Crediting" Better Site Design Practices

STEP 2: Evaluate BMP Options

Reference to Chapter 3.3 BMP Selection.
Site Characteristics/Feasibility (Table 3.6 of Chapter 3)

- Soils: Soils consist of HSG B & C soils. The area is mapped as a HSG B soil complex.
- Water Table / Bedrock
- Hydraulic Head
- Slope: mild slopes
- Drainage Area size
- Available space

The available hydraulic head (the vertical distance from the inflow elevation and the invert of the outlet system) allows for a Level 2 Bioretention design: 2 feet of bioretention soil media and an underdrain.

Select Level 2 Bioretention located in the central driveway island.

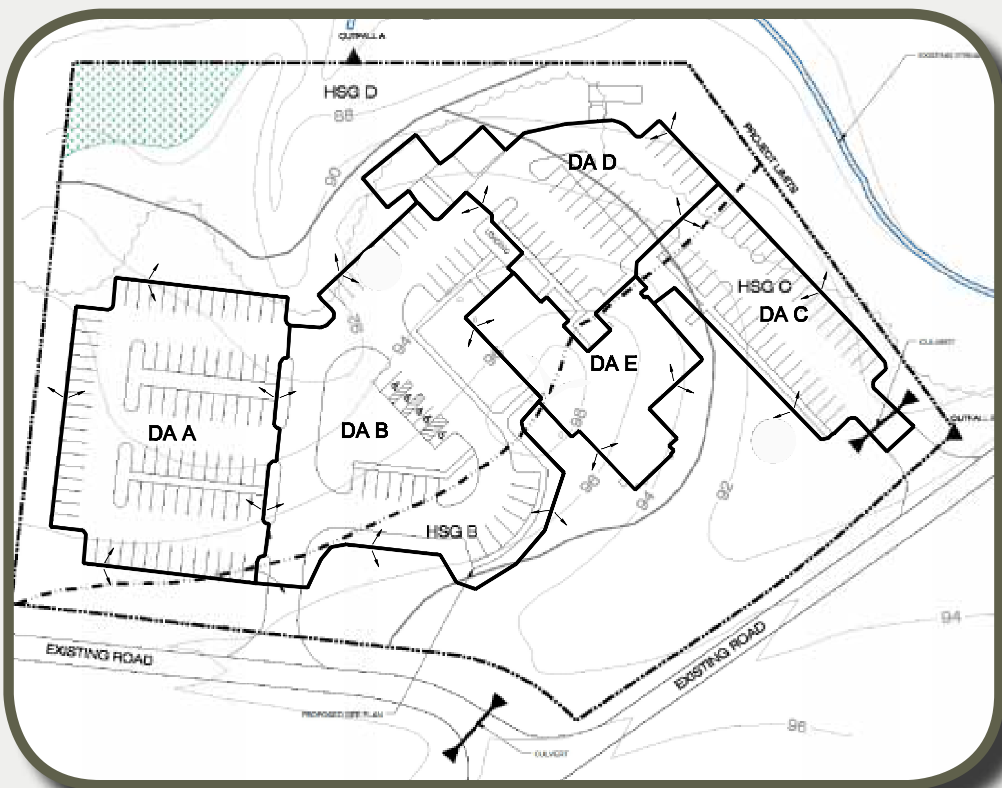


Figure 6.3.1. Drainage Areas

STEP 3: Determine BMP Drainage Areas and Treatment Volume (Tv)

Drainage Area Descriptions:

Drainage Area B consists of parking, sidewalk, and driveway area, as well as some green space in the form of managed turf adjacent to the proposed building and a minor strip of cut/fill slope adjacent to the parking and sidewalk curb and gutters. In addition, the open space reserved for the proposed bioretention area in the interior of the large parking island of Drainage Area B is considered open space.

There are several options for the treatment of the runoff from this drainage area. However, protecting the perimeter portions of the site from disturbance and maintaining them as open space will be a self-crediting measure. Also, the presence of mature hardwood trees along the western edge of the parking lot serves to discourage any grading beyond the minor fill required for the parking and curb line. Further, the grading required to drain the area to the east creates outfall and earthwork challenges. Therefore, the large parking island is identified as the optimal location for a bioretention basin.

The sub-areas of Drainage Area B provide for two inflow points into the Bioretention Basin. **Figure 6.3.2** shows the proposed grading and drainage divides, as well as the proposed stormwater entry points (curb cuts and overflow inlets) into the bioretention area.

Table 6.3.1. Drainage Area B Land Cover Data

Land Cover	Area (ft2)	Area (ac)	Percent (%) of Total
Forest/Open Space[1]	6,350	0.15	19
Managed Turf	6,088	0.14	17
Impervious	22,660	0.52	64
Drainage Area B Total	35,098	0.81	

[1]The Forest/Open Space land cover is applied to the area of the Bioretention Basin

The Treatment Volume for Drainage Area B is taken from the Site Data Tab in the West Virginia Compliance Spreadsheet or the following equation:

Equation 3.1 (Chapter 3):

$$Tv = \frac{P \times (Rv_I \times \%I + Rv_T \times \%T + Rv_F \times \%F) \times SA}{12}$$

$$Tv = \frac{1" \times (0.95 \times .64 + 0.2 \times .17 + 0 \times .19) \times 0.81}{12} = 0.043\ ac.ft = 1{,}887\ ft^3$$

STEP 4: BMP Sizing and Design

Bioretention Basin: From **Chapter 4.3.2**

Step 1: Surface ponding – For ponding depths of less than 1 foot, surface storage should account for at least 50% of the required total design volume within the practice. For ponding depths of 1 foot or more (18 inches maximum), surface storage should account for at least 70% of the total design volume.

- Select 12" surface ponding depth;
- surface ponding volume = 70% of design Tv = 0.7*1,887 ft^3 = 1,320 ft^3

Step 2: Soil media surface area and depth – The soil media and gravel layer provide the required remaining storage volume within the void spaces to manage the design treatment volume. The minimum surface area of the soil media can be derived as a function of the bottom surface area of the surface ponding volume. The ponding surface area can be larger than the surface area of the soil media as defined in Chapter 4.2.3:

  - Ponding depths < 1 ft., ponding surface area can exceed the soil media surface area by up to 50%;
  - Ponding depths ≥ 1 ft., ponding surface area can exceed the soil media surface area by up to 25%

In order to provide the most economical design, the soil media surface area will be minimized to 25% less than the ponding surface area as measured at the soil surface:

- Use Equation 4.1 from Chapter 4.2.3 to determine the average ponding surface area:
  - Surface Ponding Volume = $SA_{avg\text{-}ponding} * d_{ponding}$ = 1,320 ft^3
    - $d_{ponding}$ = 12"; $SA_{avg\text{-}ponding}$ = 1,320 ft^2
  - Approximate surface area at the bottom of the ponding depth = 1,100 ft^2 ; based on:
    - 3:1 side slopes;
    - 12" ponding depth.
- Soil media surface area = (ponding surface area bottom)/(1.25)
  = 1,100 ft^2/1.25 = 880 ft^2

Step 3: Verify Total Design Treatment Volume

- Total storage volume of the practice: Equation 4.2 from Chapter 4.2.3:

$$Dv_{practice} = SA_{bottom} \times [(d_{media} \times \eta_{media}) + (d_{gravel} \times \eta_{gravel})] + (SA_{avg-ponding} \times d_{ponding})$$

$$Dv_{practice} = 880ft^2 \times [(2' \times 0.25) + (0.75' \times 0.4)] + (1{,}320 \times 1')$$

$$Dv_{practice} = 2{,}024\ \text{ft}^3 > 1895\ \text{ft}^3 \quad \text{(Sizing is OK)}$$

Figure 6.3.2 provides the plan view of the proposed design showing the limits of:

- Surface Area of Ponding (average depth) = minimum 1,320 ft^2
- Surface Area of soil media = minimum 880 ft^2

Figure 7.3.3 provides the typical section of the Bioretention Basin.

- Ponding depth = 1 ft
- Soil media depth = 2 ft
- Gravel layer thickness = 9 inches (including 4" underdrain)

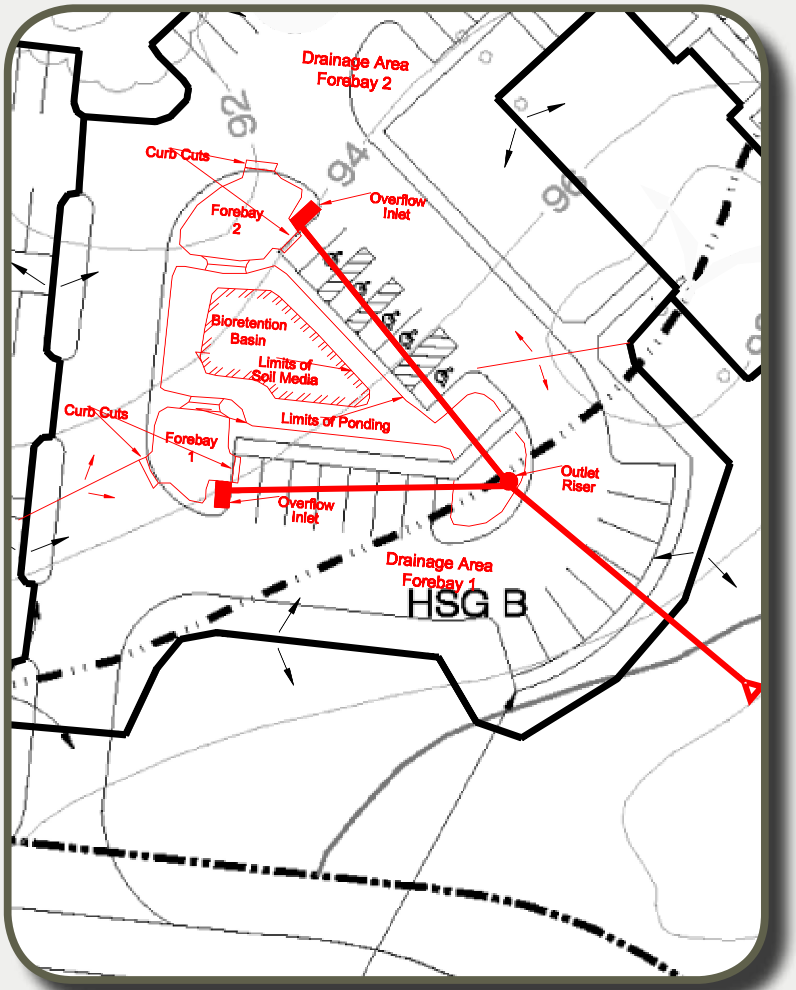


Figure 6.3.2. Bioretention Basin Plan View

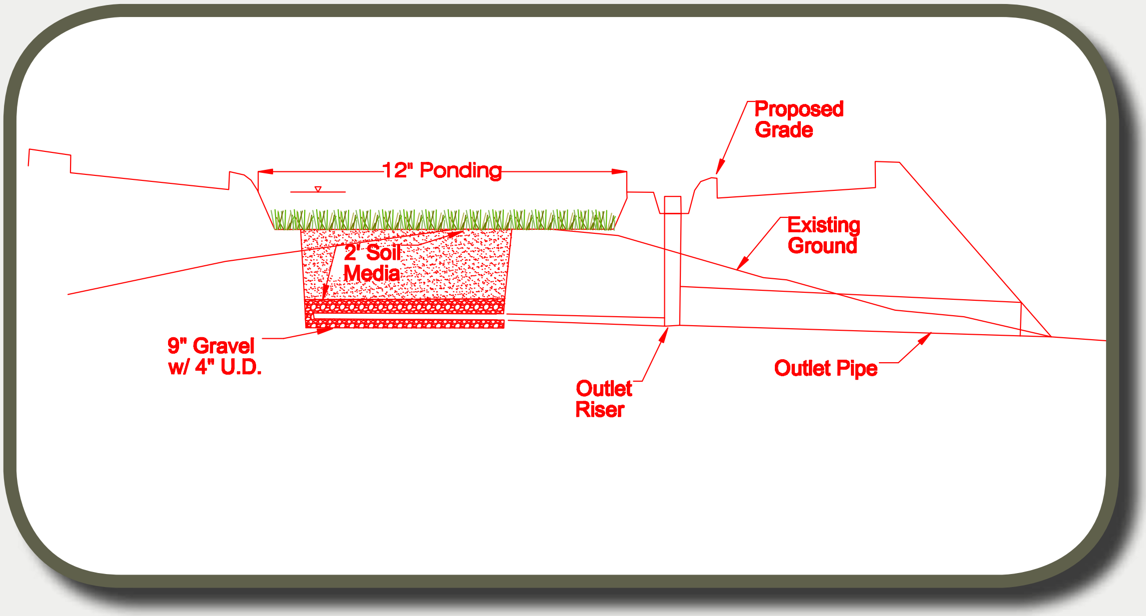


Figure 6.3.3. Bioretention Basin Section

Step 4: Design Features – Refer to Chapter 4.2.3; Design Step 4:

- Pre-Treatment Cells (or Forebays): Pre-treatment is essential for long term performance of Bioretention Basins (Refer to **Section 4.3** of **Chapter 4.2.3**). **Figure 7.3.2** shows the proposed drainage divides for Forebay 1 and Forebay 2, as well as the proposed entry points (curb cuts) into the bioretention area. The design volume for the forebays is approximated as 15% of the design treatment volume, inclusive:
    - Two curb cuts: approximately 36% of drainage area to curb cut #1; 65% to curb cut 2.
    - The 15% target volume will be proportioned between the two curb cuts.
        - Forebay 1 Volume = (0.36)*(0.15)*(2,024 ft^3) = 109 ft^3
        - Forebay 2 Volume = (0.64)*(0.15)*(2,024 ft^3) = 194 ft^3
- Geometry: The parking grading has been manipulated to position the inlet curb cuts at the farthest possible location from the proposed outlet location.
- Landscaping plan: surface cover is mulch and landscaping (**Section 4.17**);
- 4-inch perforated underdrains with choker stone layer (no sump is provided)
- Outlet Structure sized to carry the 2-year design storm, and the overflow curb inlets are sized and designed to carry the 10-year design storm (or as required by the local plan approving authority).

Step 5: Verify Compliance

The Level 2 Bioretention provides 100% runoff reduction for the design Treatment Volume. Therefore, Drainage Area 2 meets the treatment requirements.

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6.4. Design Example 4: Water Quality Swale and Grass Swale

This example continues with the site plan introduced in Example 6.1 and addresses the treatment volume generated in **Drainage Area C** as shown in **Figure 6.4.1**. Drainage Area C consists of parking lot that is gently sloped in one direction creating a BMP location along the long edge of the parking lot. The available hydraulic head (the vertical distance between the elevations of the inflow and the invert of the outlet) is severely limited in this area of the site, necessitating a minimal depth BMP.

STEP 1 Site Assessment/Narrative:

Refer to **Chapter 2.3**: General Compliance Procedure for New Development and Redevelopment Projects; and **Chapter 4.1**: "Self-Crediting" Better Site Design Practices

STEP 2: Evaluate BMP Options

Reference to **Chapter 3.3 BMP Selection**.

Site Characteristics/Feasibility (Table 3.6) was evaluated in Example 6.1. Several BMP options were considered for this drainage area:

- Vegetated Filter Strip: not enough space is available on either side of the parking area;
- Impervious Disconnection: small areas of commercial non-residential impervious can be treated with disconnection. The longest flow path criterion is met (≤ 75'); however, there is insufficient space for the disconnection (similar to the vegetated filter strip).

Select Level 1 Water Quality Swale located adjacent to the long edge of the parking lot (between the parking lot and the building).

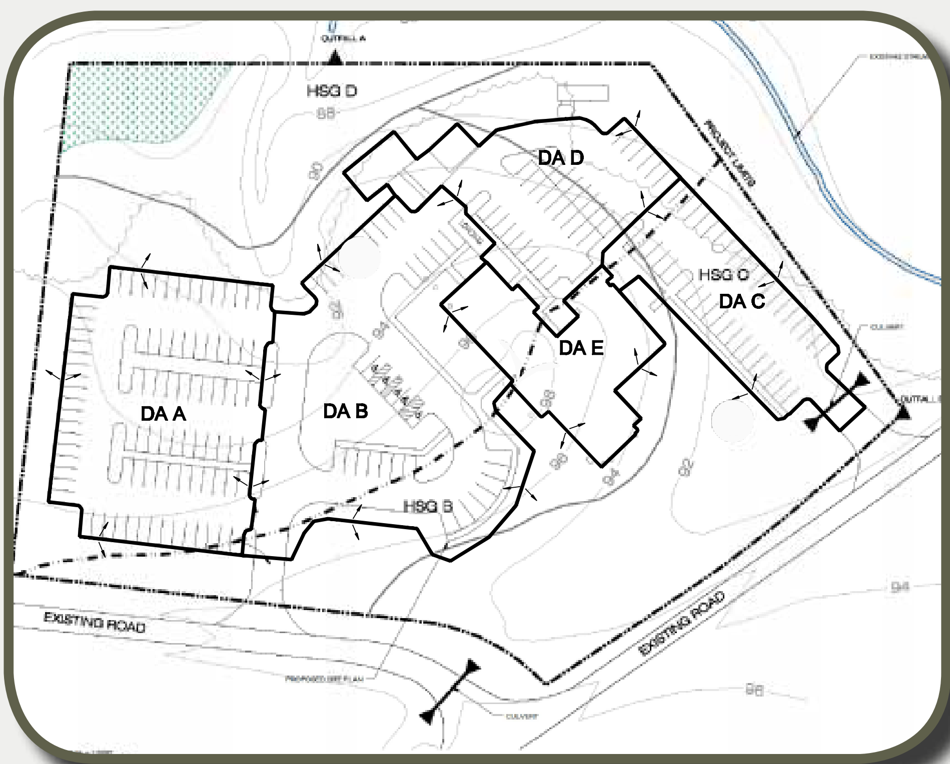


Figure 6.4.1. Drainage Areas

STEP 3: Determine BMP Drainage Areas and Treatment Volume (Tv)

Drainage Area Description:

Drainage Area C consists of two rows of parking and drive aisle, and an adjacent sidewalk. Portions of the parking area are in fill in order to create proper drainage patterns, so all the adjacent pervious areas drain away from the parking. Therefore, the entire drainage area is impervious.

Table 6.4.1. Drainage Area C Land Cover Data

Land Cover	Area (ft2)	Area (ac)	Percent (%) of Total
Forest/Open Space	0	0	0
Managed Turf	0	0	0
Impervious	12,937	0.297	100
Drainage Area 3 Total	12,937	0.297	

The parking area sheet flows across with the downhill edge of pavement serving as a level spreader into the water quality swale. The Level 1 water quality swale only achieves 55% runoff volume reduction, so it will need to be over-sized or additional runoff reduction practices in series will be required to achieve the required reductions in this drainage area. **Figure 6.4.2** shows the proposed grading and drainage pattern into the water quality swale.

The Treatment Volume for Drainage Area C is taken from the Site Data Tab in the West Virginia Site Design Spreadsheet or the following equation:

Equation 3.1 (from Chapter 3.4.1):

$$Tv = \frac{P \times (Rv_I \times \%I + Rv_T \times \%T + Rv_F \times \%F) \times SA}{12}$$

$$Tv = \frac{1'' \times (0.95 \times 1) \times 0.297}{12} = 0.023\ ac.ft = 1{,}024\ ft^3$$

STEP 4: BMP Sizing and Design

Water Quality Swale:

Step 1: Swale length, bottom width, slope, and surface ponding:

- Length is equal to parking area (180 linear feet);

- Bottom width: try 6 ft. bottom width (Level 1 can go as small as 2' to 4' bottom width; however, in order to achieve sufficient runoff volume reduction, the swale is oversized);
- Slope: 1.1% slope from each end toward the center (Level 1 can go as steep as 2% to 4%; however, in order to "daylight" the underdrain to the next BMP, a shallower grade is required;
- 12" check dams located at the center (one each side);
- Total ponding volume within the surface ponding "wedge" created by the check dams = 810 ft^3;
- Refer to **Figure 6.4.2** and **6.4.3** for Plan, Profile, and Section)

Step 2: Soil media and gravel layer depth

- Soil media depth: Level 1 Water Quality Swale requires minimum 18" soil media depth.
- Gravel layer: minimum 6" gravel over top of 4" perforated underdrain.

Step 3: Verify Total Design Treatment Volume

The total storage volume of the practice must be greater than the design Treatment Volume (and be designed according to BMP Specification 4.2.3.A) in order to achieve the full runoff reduction credit. Use a variation of Equation 4.1 from 4.2.3:

$$Dv_{practice} = SA_{bottom} \times \left[(d_{media} \times \eta_{media}) + \left(d_{gravel} \times \eta_{gravel}\right)\right] + (Surface\ Ponding)$$

Where:

$Dv_{practice}$ = total storage volume of swale (cu. ft.)
SA_{bottom} = bottom area of swale (sq. ft.) 180 ft. x 6 ft. = 1080 ft^2
d_{media} = depth of the soil filter media (ft) 1.5 ft.
η_{media} = effective porosity of the soil filter media (typically 0.25)
d_{gravel} = depth of the underdrain and gravel layer (ft) 0.833 ft.
η_{gravel} = effective porosity of the gravel layer (typically 0.40)
$Surface\ Ponding$ = Total volume within the surface ponding "wedge" (Step 1 above)

$$Dv_{practice} = 1080ft^2 \times [(1.5' \times 0.25) + (0.83' \times 0.4)] + (810ft^3)$$

$$Dv_{practice} = 1{,}573\ ft^3 > 1{,}024\ ft^3$$

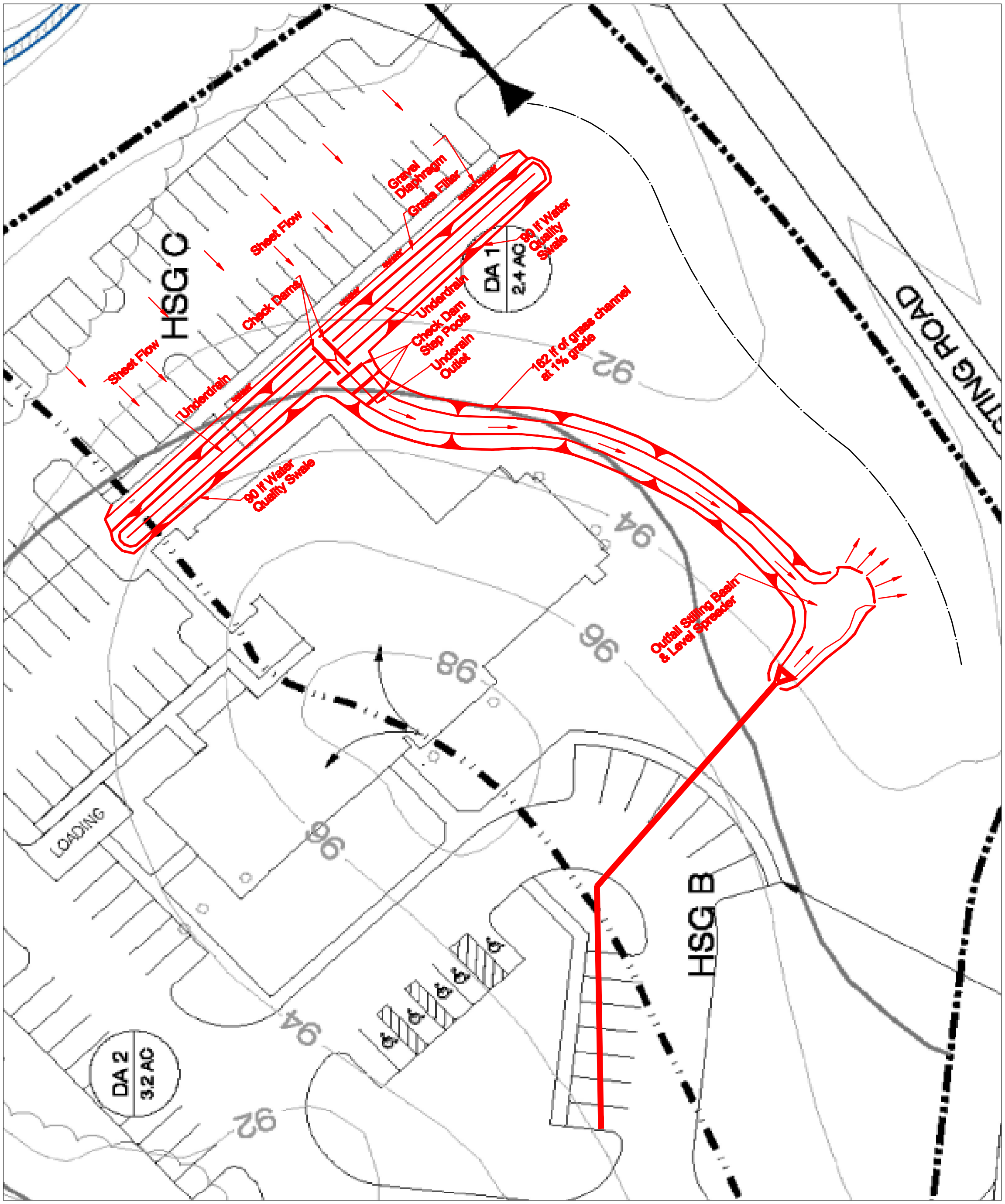
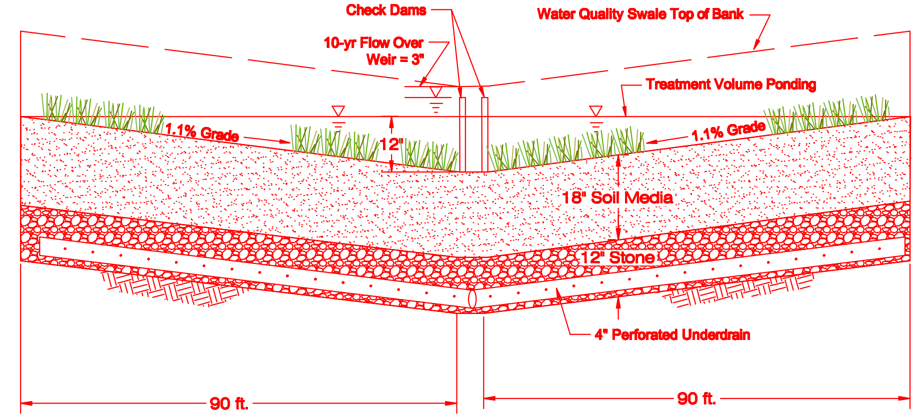


Figure 6.4.2 Drainage Area 3 with Water Quality Swale and Grass Swale



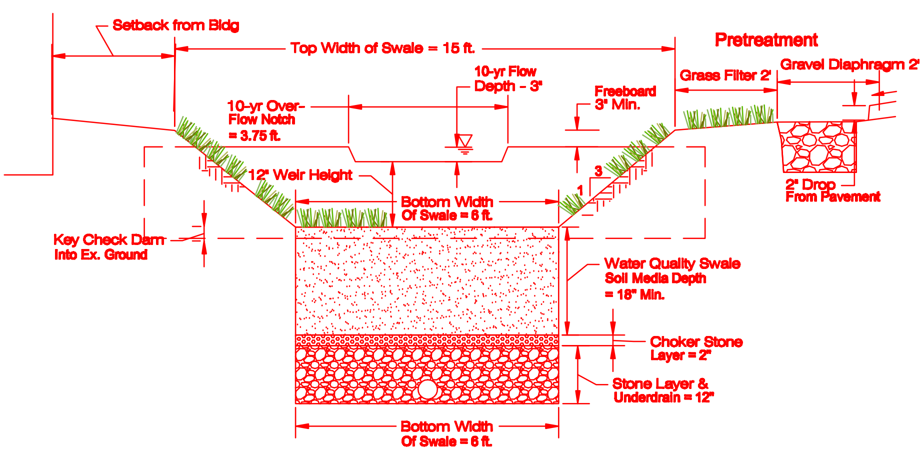


Figure 6.4.3 Water Quality Swale Profile and Typical Section with Check Dam

Step 4: Design Features

Design features for a Water Quality Swale include ensuring flow velocities are non-erosive, check dam design and overflow capacity, etc.

- Calculate the peak discharge for the 2- and 10-year design storm and the treatment volume (1" rain event)
  - Q_{10} : Rational Method Q = CIA; C = 0.8 (WVDOH Drainage Manual, Table 4-4); I_{10}= 6.1"/hr; I_2= 4.1"/hr (WVDOH Drainage Manual Chart 4-2, Appalachian Plateau; Tc = 5 min);

    Q_2= 0.8*4.1*0.297 = 1.0 cfs;

    Q_{10}= 0.8*6.1*0.297 = 1.4 cfs;
  - Q_{TV}: Modified CN Method (**Appendix E**);

    Q_{TV} = 0.3 cfs
- Verify non-erosive velocities for the 2-year storm using a channel design computer program or Manning's Equation.
- Verify 10-year freeboard requirements: Using a central notch in the check dam as a broad crested weir, compute the required length or the maximum depth of flow over the weir to carry the 10-year design storm.
  - Select a maximum design flow of 3" (0.25 ft) and compute the required width of weir.
  - **Weir Equation**: $Q = C \times L \times H^{1.5}$

    Where: Q =10-year design peak discharge = 1.4 cfs

    C = weir coefficient for broad crested weir = 3.1

    L = design length of weir (ft)

    H = design head over weir (ft) = 0.25 ft

$$Q = C \times L \times H^{1.5} = 3.1 \times L \times 0.25^{1.5} = 3.6\ ft$$

  - Use a 3.75 ft. weir notched 3 inches into check dam (Figure 6.4.3)
- Verify additional design features:
  - Underdrain diameter (4");
  - choker stone layer thickness (1"/ foot of soil media),
  - minimum swale side slopes 3:1, etc.

Step 5: Verify compliance

The Runoff Reduction credit for a water quality swale is 55%. Using the West Virginia Site Design Spreadsheet or a calculation as provided below, the remaining volume of runoff to be managed with BMPs can be calculated. While a minimum design volume is required to achieve the runoff reduction credit, the practice can be oversized to increase the runoff reduction by applying the reduction credit to the larger volume as shown below. (This is distinctly different than the crediting of Permeable Pavement as covered in Example 6.1 since additional runoff reduction credit is not achieved by over sizing the Permeable Pavement stone reservoir).

- The design Tv = 1,024 ft^3; $Sv_{practice}$ = 1,573 ft^3;
- Water Quality Swale Runoff Reduction Credit = 55%
- Calculated runoff volume reduction:

$$0.55 \times 1{,}573 ft^3 = 865 ft^3$$

- Remaining runoff volume to be treated:

$$1{,}024 ft^3 - 865 ft^3 = 159 ft^3$$

Step 6: Consider Additional Runoff Reduction BMPs

The conveyance of flow from the Water Quality Swale (surface and underdrain discharge) can be conveyed by a grass swale to the discharge point from the bioretention basin in Drainage Area B, thereby creating a single point of discharge to the receiving system along the adjacent roadway.

The grass swale will be designed with the entire contributing drainage area and corresponding peak discharges in order to compute the credit (20%) in the form of watershed-inches (0.2) rather than a percentage.

- Design Criteria for Grass Swale (Chapter 4.2.5):
  - Flow depth ≤ 4 inches; Flow velocity ≤ 1 ft/s;
  - Manning's "n" = 0.2;
  - Bottom width ≥ 2 ft; side slopes 3:1 minimum;

Step 7: Design Grass Swale

The design steps for a grass swale generally include ensuring that the design swale geometry is such that the Treatment Volume peak discharge (Q_{Tv}) meets the criteria noted above, the 2-year peak discharge is non-erosive, and the capacity design discharge (Q_{10}) is contained within the swale or bypassed thru an alternative conveyance. Given the small size of the contributing drainage area, the entire discharge will be conveyed through the swale.

- Design discharges as calculated in Step 4 above:
  - Q_{TV} = 0.3 cfs
  - Q_2 = 1.0 cfs
  - Q_{10} = 1.4 cfs;
- Equation 4.1 from Chapter 4.2.5:

$$V = \left[\left(\frac{1.49}{n}\right) D^{2/3} s^{1/2}\right]$$

D = flow depth = 0.3 ft
n = 0.2
s = 0.01 ft/ft

$$V = \left[\left(\frac{1.49}{0.2}\right) (0.3)^{2/3} (.01)^{1/2}\right] = 0.3 \, {}^{ft}/_{s}$$

- Rearranged Equation 4.2 from Chapter 4.2.5:

$$W = {}^{Q_{Tv}}/_{V \times D} = \frac{0.3}{0.3 \times 0.3}$$

$$W = 3.3 \, ft$$

- Determine minimum swale length for 9 minute residence time using Equation 4.5 from Chapter 4.2.5:

L = 540V = (540)0.3 ft/sec
L = 162 ft

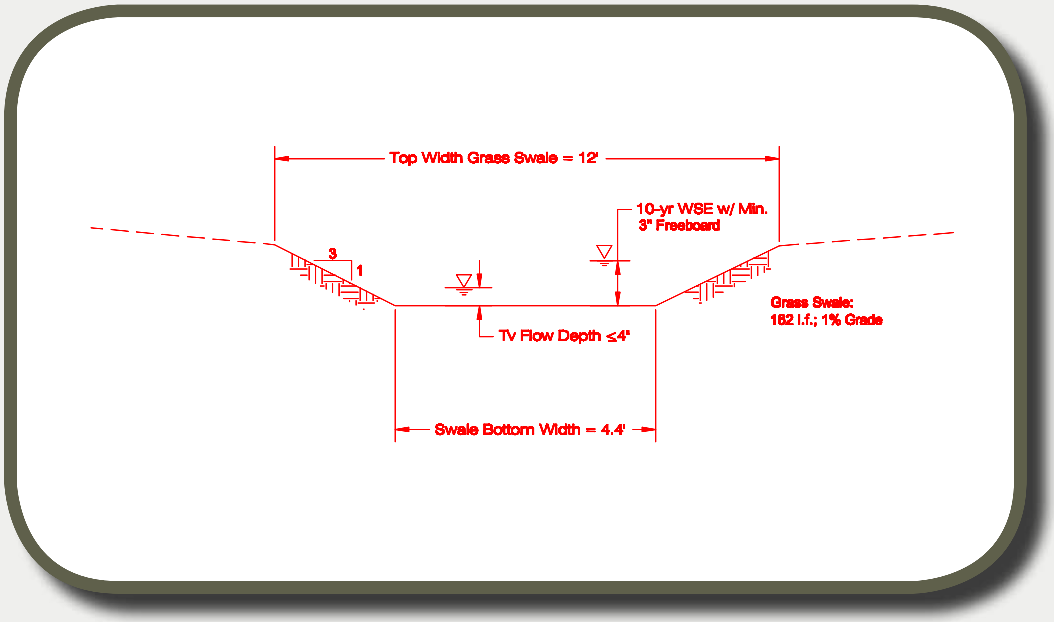


Figure 6.4.4 Grass Swale Typical Section

Step 8: Design Features

- Verify non-erosive velocities for the 2-year storm peak discharge using a channel design computer program or Manning's Equation.
- Verify the swale capacity and freeboard for the 10-year storm peak discharge using a channel design computer program or Manning's Equation.
- Refer to Figure 6.4.2 for Plan and 6.4.4 for Typical Section

Step 9:Verify compliance

- The remaining Treatment Volume = 159 ft^3 from Step 5 above.
- Runoff Reduction Volume (RRv) credit from the Grass Swale = 20% or 0.2 watershed-inches:

$$RRv = (0.2") \times (0.297ac) \times (43{,}560\, ft^2/ac) \times (ft/12") = 216 ft^3$$

- Remaining Treatment Volume = 159 ft^3 – 216 ft^3 = 0

Appendix A
Plan Review, Construction, and Maintenance Checklists

The checklists are designed as a tool for plan reviewers and design professionals to aid in the preparation and review of stormwater management plans. The intent is that local stormwater programs will modify these checklists to suit local program plan review procedures. As such, these checklists can be considered templates for the local program. The checklists are formatted in MS Excel, so they can easily be downloaded and modified.

Checklists are provided in three major categories:

1. Plan Review
2. Construction (initial installation of stormwater BMPs)
3. Maintenance

The checklists have been consolidated for several of the stormwater BMPs in the manual. The following checklists are included:

- Stormwater Concept Plan (Plan Review checklist only)
- Stormwater Final Design Plan (Plan Review checklist only)
- Sheetflow to Conservation Area and Vegetated Filter Strip (4.2.1)
- Impervious Surface Disconnection (4.2.2)
- Bioretention/Infiltration/Filtration (4.2.3, 4.2.6, 4.2.10)
- Permeable Pavement (4.2.4)
- Grass Swale (4.2.5)
- Rainwater Harvesting (4.2.8)
- Vegetated Roof (4.2.9)
- Stormwater Wetlands (4.2.11)

Please note that Regenerative Stormwater Conveyance (4.2.7) is not included in the checklists. This technology is relatively new, and there is not a lot of existing information available in checklist form. Designers and plan reviewers are encouraged to consult the following design reference for additional information on this particular BMP:

Anne Arundel County, Maryland. 2011. *Regenerative Step Pool Storm Conveyance (SPSC), Design Guidelines.* Revision 3: July 2011. http://www.aacounty.org/DPW/Watershed/StepPoolStormConveyance.cfm

Please also note that each and every detail contained in the specifications in **Chapter 4** is not included in these checklists. They provide a quick reference to ensure that essential information is included on a stormwater management plan. Designers and plan reviewers must still consult **Chapter 4** for guidance on feasibility, sizing, design, materials, construction sequence, and other features related to a particular stormwater BMP.

The checklists can be downloaded in spreadsheet format at the following link:

http://www.dep.wv.gov/WWE/Programs/stormwater/MS4/Pages/default.aspx

Appendix B

Infiltration and Soil Testing

Introduction

The goals of Runoff Reduction and compliance with the Watershed Protection Elements (Chapter 4-1) and the performance standards of Site and Neighborhood Design on new and re-development are based on having a practical understanding of the soil conditions and their hydrologic response characteristics. This is especially important in the initial layout and design of the site development infrastructure: strategically locating impervious cover over soils with low permeability (Hydrologic Soil Groups C and D), and directing runoff to soils that are highly permeability (Hydrologic Soil Groups A and B).

Accurately identifying the Hydrologic Soil Group (HSG) of the existing soils is also an important first design step in computing the design Treatment Volume (Tv) and appropriate runoff reduction credit. More importantly, drainage area runoff computations using the Natural Resources Conservation Service (NRCS) methodology require knowledge of a soil's HSG, particularly for soils with pervious land covers.

Figure B.1 Soil Profile Test Pit (photo source: Arthur J. Howland & Assoc., P.C.)

> **NOTE**: *An interactive web-based soil rating system for rating the suitability of West Virginia soils for stormwater management practices is under development. Specific soil criteria are used to develop soil suitability ratings, limitations, and recommendations for the applicability of specific stormwater BMPs. More information on this assessment tool will be made available by DEP.*

1. Site Evaluation – Initial Screening

The initial screening of the on-site soils should be conducted in conjunction with the Natural Resources Inventory (**Specification 4.1.2**). This exercise should identify basic soil characteristics related to stormwater management, such as the Hydrologic Soil Groups (HSG), as well as other features relevant to construction activities (e.g. erosion and sediment control). Also, the initial screening should identify where more detailed soil investigation and field determinations may be needed to refine the limits of the different HSGs as defined in the soil survey, or where field conditions indicate different characteristics than those indicated in the survey.

The initial screening should also include the identification of locations deemed suitable for infiltration BMPs and therefore further detailed geotechnical investigations. In general, designers should evaluate the potential for multiple small infiltration practices rather than relying on fewer large scale infiltration practices. Experience in other jurisdictions indicates that larger infiltration practices with correspondingly large contributing drainage areas experience maintenance problems due to excessive hydraulic loading (CWP 2009). Multiple smaller infiltration practices will also be less likely to have groundwater mounding problems.

Therefore, the initial screening should be broad in terms of soil types across the site, yet also detailed enough to advise the efficient implementation of more detailed soils and subsurface investigation.

> **NOTE**: *Designers must be aware of the proposed earthwork for the final development layout when conducting the Initial Screening. Areas of cut and/or fill must be carefully evaluated for structural stability in addition to any precautions with regard to stormwater management designs. Infiltration or infiltration sumps located in the vicinity of fill has the potential to compromise the stability of the fill section by creating a slip-plane.*
>
> *If the designer is not be aware of the final grading plan when developing a stormwater concept plan, he/she must coordinate the stormwater BMP type and placement with the site designer to ensure that the final locations*

are investigated and a licensed or otherwise qualified professional (as described in Section 6.a. of this Appendix) has conducted a geotechnical exploration and provided design recommendations. These recommendations must be included in the final geotechnical report as well as the stormwater management design report.

NOTE: *This guidance may not be applicable in cases where soils have been identified as having been reconstructed, such as old mining areas. Subsurface drainage and other soil suitability issues of abandoned or reclaimed minimg areas are beyond the scope of this guidance.*

2. Site Evaluation – Soil Characterization and Hydrologic Soil Groups

In accordance with NRCS recommendations, a soil's HSG is typically determined through information available in the NRCS Soil Survey. Detailed information can be found in local USDA NRCS Soil Surveys or online at the USDA NRCS Data Mart (http://soildatamart.nrcs.usda.gov). However, at certain locations, the Soil Survey does not have sufficient information to determine the HSG, or it has been mapped as Urban Land with an assumed default HSG D. It is also possible that direct soil observations or tests may indicate that a soil's HSG is different than that which is provided by the Soil Surveys due to mapping errors or the soil having been altered through cuts, fills or other disturbances.

In all cases, the designer should evaluate the existing soils to ensure a proper HSG designation for calculating the Runoff Reduction Treatment Volume, as well as any other construction related soil suitability limitations.

Soils are grouped into Hydrologic Soils Groups A, B, C, or D based on similarities in certain characteristics:

- soil texture and structure;
- depth to a restrictive layer: (i.e. soil morphological characteristics which restrict the vertical movement of water including but not limited to abrupt textural boundaries, fragipan, bedrock, dense or cemented soils);
- depth to water table;
- hydraulic conductivity or transmission rate of water; and
- degree of swelling when saturated.

The definitions of common terms used throughout the specification are provided for clarity:

Soil infiltration – the rate at which stormwater enters the soil. Infiltration is influenced by soil structure, compaction, organic matter, moisture content, and other physical characteristics at the soil surface. The design infiltration rate is usually expressed as a constant value.

Soil permeability – the rate at which stormwater flows through the soil.

> **NOTE:** *Infiltration and Permeability are used interchangeably in many reference materials.*

The infiltration and permeability of a given soil can be related to the hydraulic conductivity of the soil (K). The rate at which water enters the soil (*infiltration*), under optimal conditions, starts very fast and gradually declines and eventually approaches a constant rate. This constant rate of infiltration is sometimes called the soil's permeability, but is technically defined as the ***saturated hydraulic conductivity*** (*Ksat*). In almost all cases, reference to an infiltration rate or permeability implies this long-term constant rate (permeability, *Ks* or *Ksat*). (Jarrett, 2008).

The property that is most limiting to water movement generally determines the soil's hydrologic group. (USDA NRCS, May 2007)

For example, in terms of soil texture, Group C soil includes silt loam and sandy clay loam and is typically between 20 percent and 40 percent clay and less than 50 percent sand. There are some overlaps where the texture classes may include a range of sand-silt-clay fractions in one HSG and the same texture name with a slightly different fraction in a different HSG. For example, soils having clay, silty clay, or sandy clay texture (typically grouped in HSG D) may be placed in Group C if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

Equally important are the defining physical characteristics of the group: the depth to a restrictive layer or water table, and saturated hydraulic conductivity. For Group C, the depth to any water impermeable layer is greater than 20 inches, and the depth to the water table is greater than 24 inches. Soils that are deeper than 40 inches to a restriction or water table are in Group C if the saturated hydraulic conductivity of all soil layers within 40 inches of the surface is less than 0.57 inches per hour (but exceeds 0.06 inches per hour). The saturated hydraulic conductivity in the least transmissive layer between the surface and 20 inches is between 0.14 in/hr and 1.42 in/hr.

In very general terms, water transmission through C soils is *somewhat* restricted, and they have moderately high runoff potential when thoroughly wet. A general definition of the HSG is provided:

> Group A. Soils with low runoff potential. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep well drained to excessively well-drained sands or gravels and have a high rate of water transmission.

Group B. Soils having moderate infiltration rates even when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well drained to well drained soils with moderately fine to moderately coarse textures and have a moderate rate of water transmission .

Group C. Soils having slow infiltration rates even when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures and have a slow rate of water transmission .

Group D. Soils with high runoff potential. Soils having very slow infiltration rates even when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material and have a very low rate of water transmission.

NOTE: *Readers are encouraged to refer to* ***National Engineering Handbook Chapter 7: Hydrologic Soil Groups****, and the* ***USDA Soil Survey Manual, Chapter 3*** *for detailed guidance on the application of soil classification criteria for determining the hydrologic group of a particular soil based on the characteristics observed and recorded from the soil profile pits and soil borings: soil texture, bulk density, depth to water table (or other restrictive layer), and if available, the saturated hydraulic conductivity.*

"Restrictions" in the soil profile are defined in the 1996 National Soil Survey Handbook and include, but are not limited to the presence of bedrock, dense material, fragipans, and ortsteins. The seasonally high water table is based on either observed saturation or redoxomorphic features. The presence and depth of these restrictions must be included in the soil logs.

Table B.1 provides guidelines for the number of soil test pits and soil borings for identifying and classifying soils on a development site (**Section 3** below provides additional information on the soil borings and profile pits). The lead investigator should evaluate the available soil survey information and compare it with site visit observations to determine if more soil exploration than that noted below will be required for accurate classification.

Table B.1. Soil Explorations Required for Hydrologic Soil Group Classification

Mapping unit or DA size		
< 0.5 ac	**> 0.5 ac; < 2.0 ac**	**> 2 ac**
1 Soil Profile Pit 1 Soil Boring	1 Soil Profile Pit 4 Soil Borings	1 additional Soil Profile Pit[1] 2 additional Soil Borings[1]

1 For each additional 2 acres

3. Site Evaluation: Soil Testing for Infiltration BMPs

Where infiltration of runoff into the existing soil strata is part of the selected BMP runoff reduction strategy, the designer must determine the actual soil permeability (or saturated hydraulic conductivity) through field tests. The failure of stormwater infiltration devices is often attributed to an inaccurate estimation of the design infiltration rate and/or depth to the seasonal high water table or other limiting layer.

There are also numerous examples of infiltration BMP failures attributed to a lack of sediment control or other protections during construction, or inadequate runoff pretreatment and long term maintenance. However, those deficiencies are addressed through better design, construction, and operation and maintenance guidance. The purpose of this guidance is to provide clear expectations for the number and type of soil tests required in order to ensure that the individual infiltration practice is appropriate for specific site location.

The goal of the soil tests are to establish detailed information on groundwater conditions and physical characteristics of the soil to determine the suitability of the soil for a stormwater infiltration BMP. Soil testing will include soil test pits, soil borings, and soil infiltration tests.

A soil test pit is an excavation made for the purpose of exposing and evaluating the soil profile, and for conducting a soil permeability test at the appropriate depth. Data recorded in each reference test pit is to be compared to the soil profile described in the adjacent soil boring(s) to confirm consistence between the test pit and the boring. Where soil and/or groundwater properties vary significantly between soil boring and profile pit explorations, additional soil profile pits should be conducted as necessary to resolve such differences and accurately characterize the soils in the area of interest.

In areas where a soil profile pit would substantially disturb the existing area and create an undesirable condition or where significant environmental disturbance will occur in an area that is not intended for future development, two soil borings may be conducted in the place of a required soil profile pit with a soil profile pit located at the closest available location representative of the soil boring locations. If the location of the soil profile pit is not representative of the soil borings taken, it is the responsibility of the design engineer to demonstrate the consistency of soil profile pit data to the soil characteristics at the location of the soil borings.

Number and location of soil explorations:
A Soil profile pit and soil borings are only required in the areas of the BMP being utilized for infiltration. (Additional soils exploration may be necessary if the designer needs to verify the site HSGs for runoff and Tv calculations.) Where only a portion of the BMP's bottom is being utilized for infiltration, the infiltration area is applicable only to that portion of the BMP. Placement of soil test pit shall be such that it provides adequate characterization of the infiltration area.

- 1 soil profile pit shall be excavated within the infiltration area of any proposed infiltration BMP up to 2,500 ft^2 in area;
- 2 soil profile pits and 2 soil borings for BMP infiltration areas between 2,500 ft^2 and 5,000 ft^2 in area;
- 2 soil profile pits and 3 soil borings for BMP infiltration areas larger than 5,000 ft^2 in area;
- 1 additional soil profile pits and 2 additional soil borings for each increase in infiltration surface area of 5,000 ft^2.

The total number of required soil profile pits shall be placed generally equidistant from each other so as to provide adequate characterization of the infiltration area.

For linear infiltration BMPs (infiltration area length to width ratio of 4 to 1):

- 1 soil profile pit shall be excavated in a representative 100 ft section of the infiltration area;
- 1 additional soil profile pit and 1 soil boring within each additional 200 ft section of infiltration area.

For sites with multiple infiltration BMPs each with surface areas less than 500 square feet, a minimum of one (1) soil profile pit is required for the site and one soil boring per infiltration BMP. In doing so, the test pit must be properly located within the overall site to adequately depict site soil conditions. Where soil and/or groundwater properties vary significantly between soil explorations, additional soil profile pits shall be conducted as necessary to resolve such differences and accurately characterize the soils. For infiltration practices associated with single family residential development, only one soil boring is required per lot.

NOTE: *If there are notable inconsistencies between the soil profiles and the profile pit within the area of any one or multiple infiltration locations, it is the responsibility of the design engineer to ensure a sufficient number of soil explorations are conducted to ensure an accurate representation of the soil conditions.*

Depth of Test Pits and Soil Borings

In order to evaluate the infiltrative capacity of the soils at the location of the proposed infiltration BMP, soil borings and test pits should be to a depth of 3 feet below the bottom of the BMP, or a depth of two times the maximum potential water depth in the BMP below the proposed surface of the BMP, whichever is greater.

Where soil replacement below the bottom of the BMP is proposed, the test pit and/or soil boring should extend below the depth of soil replacement to a depth equal to two (2) times the maximum potential water depth within the basin or 3 feet below the bottom elevation of the soil replacement, whichever is greater.

Documentation of the soil test pits and soil borings

The location of the soil explorations must be shown on a legible site plan/map that is:

- Is drawn to scale or fully dimensional.
- Illustrates the location of the infiltration devices.
- Shows the location of all pits and borings.
- Shows distance from infiltration devices to wetlands, or other sensitive features.

NOTE: *Contractors must contact the West Virginia Miss Utility One-Call System (811) prior to the excavation of test pits or soil borings in accordance with Section XIV: West Virginia Chapter 24-C.*

Soil Logs

A soil log shall be prepared for each soil profile pit and soil boring in accordance with ASTM D 1452 Practice for Soil Investigation and Sampling Auger Borings & ASTM D 1586 - Test Method for Penetration Test and Split-Barrel Sampling of Soils. The soil boring log shall, at a minimum, provide the following:

a. elevation of the existing ground surface and elevations of permeability test locations;

b. the depth and thickness of each soil horizon and the depth to the substratum;

c. the dominant matrix or background and mottle colors, abundance, size, and contrast using the Munsell system of classification for hue, value and chroma;

d. the appropriate textural class as shown on the USDA textural triangle;

e. the volume percentage of coarse fragments larger than two (2) millimeters in diameter;

f. soil structure, particle sizes, and shape;

g. the soil moisture condition, using standard USDA classification terminology;

h. the presence of any soil horizon, substratum or other feature that exhibits an in-place permeability rate less than one (1) inch per hour;

i. the depth and occurrence of soil restrictions including, but not limited to, abrupt textural boundaries likely to restrict the movement of water, fragipans, dense materials, bedrock, and ortstein;

j. the depth to the seasonally high ground water level, either perched or regional;

k. any observed seepage or saturation.

The results and locations of all soil profile pits, borings and soil permeability tests, both passing and failing, should be included in the Stormwater Management Report submitted to the appropriate review agency. All soil evaluations, including test profile pits, soil borings, and permeability tests shall be conducted under the supervision of a licensed Soil Scientist or other licensed professional acceptable to the authority having jurisdiction.

4. Soil Permeability Testing

Soil permeability can be determined by one of two methods:

a. Permeability tests performed at each soil profile pit; or

b. Permeability determined by field verifying the USDA Soil Texture Class and bulk density of the most restrictive layer as recorded in the soil test pits and soil borings, and selecting the corresponding saturated hydraulic conductivity from **Table B.1.**

<u>Permeability Tests</u>
Permeability tests must be conducted at the most restrictive layer between the bottom elevation of the proposed infiltration BMP and a depth of 3 feet below the bottom, or two times the maximum potential water depth in the BMP, whichever is greater. For example, permeability tests for a bioretention basin that is proposed to be 4 feet in depth with a maximum potential water depth of 4.5 feet should be conducted at the most restrictive layer between a depth of 4 feet and the greater of 7 feet or two times the water depth, or 9 feet, below the surface.

Where stormwater infiltration BMPs are in proximity to fractured bedrock, there should be a minimum of two feet of soil between the bottom of the infiltration BMP and the bedrock. Where the permeability rate of the bedrock is critical to the function of the basin, the design engineer shall demonstrate that appropriate testing methods as discussed in **this section** are utilized to establish the permeability rates of the infiltration BMP.

The number of permeability tests for fractured bedrock should be no less than the tests required for permeability in the soil. The design permeability rate of 0.5 in/hr can be used for bedrock when the basin drains completely within 12 hours during a basin flood test performed as described in this guidance. To use permeability rates greater than 0.5 in/hr, more detailed testing is required.

The following tests are acceptable for use in determining soil infiltration rates. Other tests may be allowed at the discretion of the local plan approving authority. The Geotechnical Report shall include a detailed description of the test method and published source references:

- Tube Permeameter Method (ASTM D 2434);
- Double-Ring Infiltrometer (ASTM D 3385);
- Basin flooding test for bedrock (refer to **Section 5** of this Appendix);
- Percolation Test (64CSR47 - §64-47-6.6.3); or
- other constant head permeability tests that utilize in-situ conditions and accompanied by a recognized published source reference.

<u>USDA Soil Texture Classes</u>

The permeability or saturated hydraulic conductivity of a soil can be measured directly using the tests noted above, or estimated indirectly from the soil texture data collected through the soil profile test pits or soil borings. The following information has been excerpted from Rawls et al. 1998, and provides designers with a conservative estimate of the saturated soil conductivity based on the USDA Soil Texture Classes and bulk density. This may save some time and expense in field testing; however it is admittedly an estimate and may yield a lower or more conservative conductivity and therefore potentially increase the size (or eliminate altogether) any proposed infiltration practices that would otherwise be designed with field verified infiltration tests.

Table B.2 provides the *Saturated Hydraulic Conductivity* for soils classified by USDA Soil Texture Classes and further divided into two bulk density classes according to whether the bulk density was above or below a given value recommended by NRCS.

The bulk density of a soil has a measureable effect on hydraulic conductivity (K_s) (Rawls et al.,1992). Typically as bulk density increases (or porosity decreases), the K_s

decreases. There are some exceptions to this rule, as evidenced by the K_s values for loam and silty clay loam. These values are derived from Rawls et al. 1998, and represent the geometric mean of soil data collected as part of a national data base. The exceptions noted are potentially a result of the variability in the data.

It is important to note that the ultimate long term performance of the infiltration BMP is dependent on a good design that is based on accurate supporting soils data. Designers and developers should consider the long term performance and the operation and maintenance costs in present dollars when electing to forgo the more accurate field infiltration tests.

5. Basin Flooding Test

A Basin flooding test can be utilized to establish the permeability rates of bedrock in accordance to the procedures below. The basin flooding test shall not be conducted in rock strata which have been blasted with explosives.

a. Equipment Requirements

The following equipment is required for performing a Basin flooding test:

- Excavating equipment capable of producing a test basin as prescribed in b below;
- A water supply (minimum of 375 gallons per basin filling); and
- A means for accurately measuring the water level within the basin as required in ‘c’ below.

b. Test Basin Preparation

The test basin shall be prepared in accordance with the following:

- A test basin meeting the following requirements shall be excavated within or immediately adjacent to the area of concern.
- The bottom area of the basin shall be a minimum of 50 square feet.
- The bottom of the basin should be made as level as possible so that high areas of rock do not project above the water level when the basin is flooded as prescribed in ‘c’ below.
- If groundwater is observed within the test basin, the basin flooding test shall not be used.

Table B.2. Saturated Hydraulic Conductivity Classified by USDA Soil Texture Classes and Bulk Density (Source: Rawls et al. 1998)

Soil Group	Soil Texture[1]	Bulk Density (lb/ft^3)	Design Infiltration Rate without Measurement (in/hr)[2]
A	Coarse sand, Sand	> 97	7.16
		< 97	3.60
A	Loamy sand	> 97	4.84
		< 97	1.63
B	Sandy loam	> 97	2.20
		< 97	0.50
B	Loam	> 90	0.15
		< 90	0.24
C	Silt loam	> 90	0.57
		< 90	0.13
C	Sandy clay loam	> 97	0.30
		< 97	0.11
D	Clay loam	> 94	0.17
		< 94	0.03
D	Sandy clay		0.04
D	Silty clay		0.07
D	clay		0.07

[1] For fine sand texture – use loamy sand; for loamy fine sand texture – use sandy loam; for fine sandy loam texture – use loam;

[2] Geometric mean of saturated hydraulic conductivity of all samples taken

c. Basin Flooding Testing Procedure

The following procedure shall be used to conduct the Basin Flooding test:

- *Step One:* Fill the test basin with exactly 12 inches of water and record the time. Allow the basin to drain completely. If the time required for the basin to drain completely is greater than 24 hours, the test shall be terminated and the limiting zone in question shall be considered to be a massive rock substratum.

- *Step Two:* If the basin drains completely within 24 hours after the first flooding, immediately refill the basin to a depth of 12 inches and record the time. If the basin drains completely within 24 hours of the second filling, the limiting zone in question shall be considered to be fractured rock substratum. If water remains in the basin after 24 hours the limiting zone in question shall be considered to be a massive rock substratum.

d. Permeability Rate Determination

A design permeability rate shall only be used if the basin drains completely within 12 hours while performing Step Two described in 'c' above. The design permeability rate used shall be 0.5 in/hr.

6. Additional Considerations

The following are general considerations that should be included in the development of the infiltration BMP design:

a. **Qualifications:** Soil Evaluations - Individuals completing the soils evaluation should be either a Soil Scientist licensed by the West Virginia Department of Regulation and Licensing, or be a Full Member in good standing with the West Virginia Association of Professional Soil Scientist (http://www.wvapss.org)

b. **Infiltration BMP**s should not be constructed until after all upstream areas have been adequately stabilized. If this is not possible, multiple levels of construction erosion and sediment controls should be used to protect the infiltration area and to prevent sediment laden runoff from entering the facility. This includes temporary erosion controls for site grading as well as home building and construction, as well as long term measures that will protect the infiltration area through at least two growing seasons.

c. The approval process requirements for development sites vary across the state and may also vary within a municipality depending on the size of the development (number of lots, square footage of disturbance). The timing of the Natural Resources Inventory and the follow-up field verification in conjunction with preliminary plan, stormwater concept plan, and final design plan may be dictated by the local plan approving process.

It is recommended that the Natural Resources Inventory be completed before the preliminary site design. The follow-up field verification should be completed concurrently with the stormwater concept plan (use the stormwater concept plan to direct the field investigation.

REFERENCES

ASTM D 1452 Practice for Soil Investigation and Sampling Auger Borings & ASTM D 1586 - Test Method for Penetration Test and Split-Barrel Sampling of Soils.

ASTM D 3385 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer, 2003.

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Appendix C

Stormwater Management Design in Karst Areas

Figure C.1. Classic karst terrain north of Lewisburg, WV. *Courtesy William K. Jones.*

The effect of land development on karst terrain is an inexact science. Karst geology is very complex and difficult to analyze due to the highly variable subsurface conditions. Even a professional analysis may not identify the potential influence of manipulating the hydrology and surface runoff patterns in areas of karst topography. However, there is increasing pressure to develop land in these sensitive areas. Therefore, in an effort to provide the most up to date guidance on evaluating and protecting this sensitive and valuable resource, the Chesapeake Stormwater Network (CSN) Technical Bulletin No. 1: *Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed*, latest version, is adopted by reference.

The Technical Bulletin is intended to be a dynamic document that can be updated over time to reflect new research, experience, and project implementation. It is important to note that the potential for geological hazards, damage to infrastructure, and groundwater contamination is an ongoing concern when developing in these areas. And that best approach is to craft stronger comprehensive land use plans that direct new growth away from karst areas to more appropriate locations. It is also recognized that there may be situations where an entire community is underlain by karst. It is therefore critical to implement rigorous geotechnical investigation requirements aimed at minimizing the impacts of land development on the natural drainage patterns.

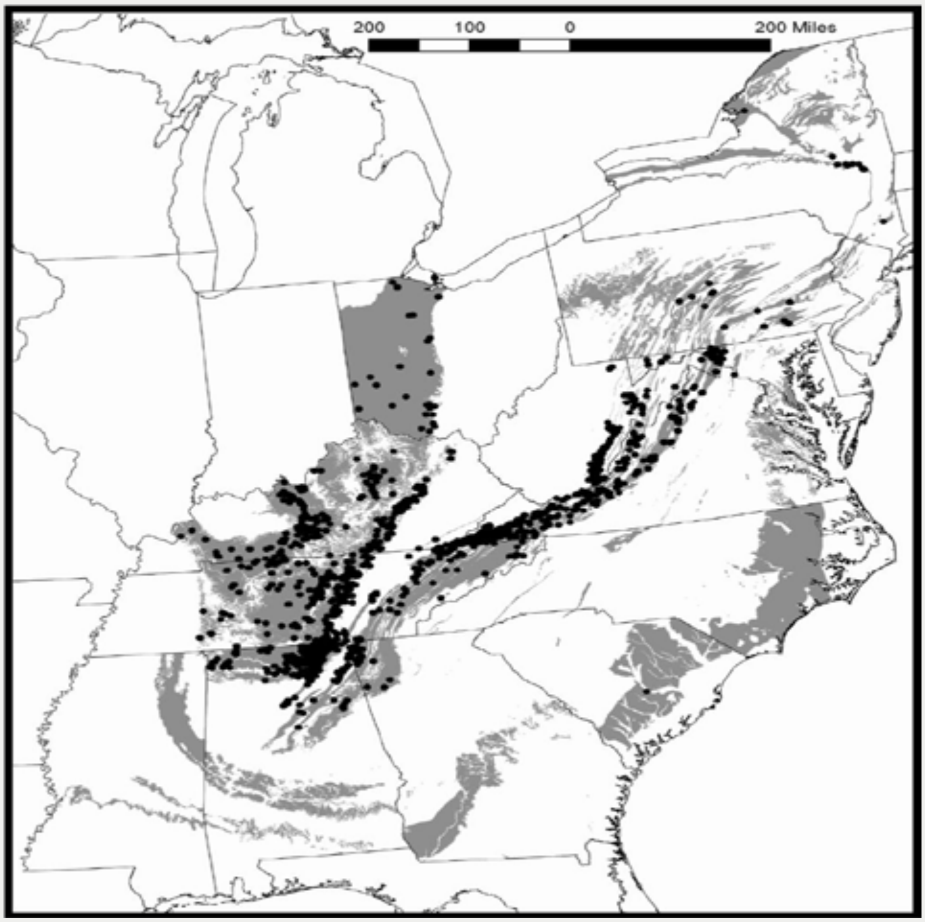

Figure C.2 Karst Terrain Distribution: grey = karst, black = caves
(Source: CSN Technical Bulletin; Weary, 2005)

Stormwater Runoff in Karst

One of the most obvious characteristics of karst geology is the absence of surface runoff features. In an extreme example, a drainage area will appear to drain (sheet flow) to a low point with no apparent outlet. A less obvious example is a large area that drains to a small road or driveway culvert. Both examples illustrate the very common occurrence in areas of karst terrain where the pre-developed runoff for small storms (up to the 1- or 2-year storm event) is minimal. Anecdotal evidence will reveal that there is rarely any flooding or surface ponding even though the best hydrologic models, based on traditional soil types and rainfall patterns, indicate otherwise.

This is a very common design issue when developing a stormwater management strategy that is intended to mimic the pre-developed hydrology. The addition of impervious cover in the form of rooftops, driveways, roads, and possibly parking lots and other larger scale infrastructure generates a significant increase in runoff without the typically available surface conveyance features to move the runoff to an adequate receiving channel or stream. Inevitably, the design will include retention, detention, or other form of runoff attenuation which is generally not recommended in the vicinity of karst terrain: attenuating surface runoff will increase the rate of sinkhole formation and potential groundwater contamination.

> **NOTE**: *The pre-developed rates and volume of runoff are generally less than most hydrologic models predict. Designers should be very cautious when using pre-developed conditions as a baseline target for stormwater designs.*

Preliminary and Detailed Site Investigations

Appendix B provides a detailed discussion of the geotechnical investigation required when considering infiltration or infiltration sump runoff reduction BMPs. The typical geotechnical investigation for exploring potential karst terrain is more detailed and will require the direct involvement of an experienced professional knowledgeable in karst terrain.

In addition to the geotechnical exploration described in Appendix B, the following are outlined in CSN Technical Bulletin 1 as minimal elements of an evaluation of potential karst geology:

- Bedrock characteristics (e.g., type, geologic contacts, faults, geologic structure);
- Photo-geologic fracture trace map;
- Bedrock outcrop areas;
- Sinkholes, closed depressions, grikes and solution-enlarged voids;
- Cave openings;
- Springs;

There are many different techniques to reveal the nature of subsurface conditions in karst terrain, including:

- Electric resistivity tomography
- Seismic refraction
- Gravity surveys
- Electromagnetic (EM) inductance/conductivity surveys

Electric resistivity tomography has proven to be a particularly useful technique to identify subsurface anomalies at a scale that impacts stormwater design. These surveys provide a qualitative evaluation of the site area and may identify "suspect areas" to be further evaluated by borings. The use of these surveys may reduce the total number of soil borings by narrowing down the locations of suspect areas at the site.

Distributed Stormwater BMPs

The effectiveness of the runoff reduction design strategy is enhanced by the use of distributed small scale practices. This is consistent with one of the stormwater design principles for karst areas: Treat runoff as sheet flow in a series of small runoff reduction practices before it becomes concentrated. This includes small scale runoff reduction practices such as bioretention basins (or raingardens) with underdrains to minimize groundwater interaction. The use of large centralized stormwater practices (generally any practice that manages runoff from a contributing impervious area of greater than 20,000 ft^2) is discouraged (even when using a liner) as it will generally include larger collection and outfall system, thereby requiring a more extensive geotechnical investigation.

CSN Technical Bulletin 1 provides a full range of stormwater design principles for use in karst areas including:

- Site Design;
- BMP Selection
- BMP Design Adaptations
- Modeling
- Large Storm Conveyance

The CSN Technical Bulletin also provides Karst-Related Digital Geospatial Data Sources. The CSN Technical Bulleting can be found on DEP's website here:

Or to ensure the latest edition, please refer to the CSN website:

http://chesapeakestormwater.net/2012/03/technical-bulletin-no-1-stormwater-design-guidelines-for-karst-terrain/

Appendix D

Soil Amendments

Soil amendment (also called soil restoration) is a technique applied after construction to deeply till compacted soils and restore their porosity by amending them with *compost*. These soil amendments can reduce the generation of runoff from compacted urban lawns and may also be used to enhance the performance of impervious cover disconnections and grass channels.

D.1. Feasibility Criteria and Design Considerations

Amended soils are suitable for any pervious area where soils have been or will be compacted by the grading and construction process. They are particularly well suited when existing soils have low infiltration rates (HSG C and D) and when the pervious area will be used to filter runoff (downspout disconnections and grass channels). The area or strip of amended soils should be hydraulically connected to the stormwater conveyance system. Soil amendment is recommended for sites that will experience mass grading of more than a foot of cut and fill across the site.

Soil amendments are not recommended where:

- Existing soils have high infiltration rates (e.g., HSG A and B), although compost amendments may be needed at mass-graded B soils in order to maintain infiltration rates.
- The water table or bedrock is located within 1.5 feet of the soil surface.
- Slopes exceed 10%.
- Existing soils are saturated or seasonally wet.
- They would harm roots of existing trees (keep amendments outside the tree drip line).
- The downhill slope runs toward an existing or proposed building foundation.
- The contributing impervious surface area exceeds the surface area of the amended soils.
- Soil amendments are not recommended for areas that will be used for snow storage.

Soil amendments can be applied to the entire pervious area of a development or be applied only to select areas of the site to enhance the performance of runoff reduction practices. Some common design applications include:

- Reduce runoff from compacted lawns.

- Enhance performance of impervious cover disconnections on poor soils.
- Increase runoff reduction within a grass channel.
- Increase runoff reduction within a vegetated filter strip.
- Increase the runoff reduction function of a tree cluster or reforested area of the site.

D.2. Design Criteria

Performance When Used in Conjunction with Other Practices. As referenced in several of the specifications, soil amendments can be used to enhance the performance of allied practices by improving runoff infiltration. The specifications for each of these practices contain design criteria for how soil amendments can be incorporated into those designs:

- Impervious Surface Disconnection – see **Specification 4.2.2**
- Grass Swales – see **Specification 4.2.5**

Soil Testing. Soil tests are required during two stages of the compost amendment process. The first testing is done to ascertain pre-construction soil properties at proposed amendment areas. The initial testing is used to determine soil properties to a depth 1 foot below the proposed amendment area, with respect to bulk density, pH, salts, and soil nutrients. These tests should be conducted every 5000 square feet, and are used to characterize potential drainage problems and determine what, if any, further soil amendments are needed.

The second soil test is taken at least one week after the compost has been incorporated into the soils. This soil analysis should be conducted by a reputable laboratory to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth. This soil analysis should be done in conjunction with the final construction inspection to ensure tilling or subsoiling has achieved design depths.

Determining Depth of Compost Incorporation. The depth of compost amendment is based on the relationship of the surface area of the soil amendment to the contributing area of impervious cover that it receives. **Table D.1** presents some general guidance derived from soil modeling by Holman-Dodds (2004) that evaluates the required depth to which compost must be incorporated. Some adjustments to the recommended incorporation depth were made to reflect alternative recommendations of Roa Espinosa (2006), Balousek (2003), Chollak and Rosenfeld (1998) and others.

Table D.1. Short-Cut Method to Determine Compost and Incorporation Depths				
	Contributing Impervious Cover to Soil Amendment Area Ratio [1]			
	IC/SA = 0 [2]	**IC/SA = 0.5**	**IC/SA = 0.75**	**IC/SA = 1.0** [3]
Compost (in) [4]	2 to 4 [5]	3 to 6 [5]	4 to 8 [5]	6 to 10 [5]
Incorporation Depth (in)	6 to 10 [5]	8 to 12 [5]	15 to 18 [5]	18 to 24 [5]
Incorporation Method	Rototiller	Tiller	Subsoiler	Subsoiler

Notes:
[1] IC = contrib. impervious cover (sq. ft.) and SA = surface area of compost amendment (sq. ft.)
[2] For amendment of compacted lawns that do not receive off-site runoff
[3] In general, IC/SA ratios greater than 1 should be avoided
[4] Average depth of compost added
[5] Lower end for B soils, higher end for C/D soils

Once the area and depth of the compost amendments are known, the designer can estimate the total amount of compost needed, using an estimator developed by TCC (1997):

$$C = A * D * 0.0031$$

Where: C = compost needed (cu. yds.)
A = area of soil amended (sq. ft.)
D = depth of compost added (in.)

D.3. Compost Specifications

The basic material specifications for compost amendments are outlined below:

- Compost shall be derived from plant material and provided by a member of the U.S. Composting Seal of Testing Assurance (STA) program. See www.compostingcouncil.org for a list of local providers.
- The compost shall be the result of the biological degradation and transformation of plant-derived materials under conditions that promote anaerobic decomposition. The material shall be well composted, free of viable weed seeds, and stable with regard to oxygen consumption and carbon dioxide generation. The compost shall have a moisture content that has no visible free water or dust

produced when handling the material. It shall meet the following criteria, as reported by the U.S. Composting Council STA Compost Technical Data Sheet provided by the vendor:

a. 100% of the material must pass through a half inch screen
b. The pH of the material shall be between 6 and 8
c. Manufactured inert material (plastic, concrete, ceramics, metal, etc.) shall be less than 1.0% by weight
d. The organic matter content shall be between 35% and 65%
e. Soluble salt content shall be less than 6.0 mmhos/cm
f. Maturity should be greater than 80%
g. Stability shall be 7 or less
h. Carbon/nitrogen ratio shall be less than 25:1
i. Trace metal test result = “pass”
j. The compost must have a dry bulk density ranging from 40 to 50 lbs./cu. ft3.

In general, fresh manure should not be used for compost because of high bacteria and nutrient levels. If manure is used, it must be aged (composed) and meet the criteria listed above.

D.4. Construction Sequence

The construction sequence for compost amendments differs depending whether the practice will be applied to a large area or a narrow filter strip, such as in a rooftop disconnection or grass channel. For larger areas, a typical construction sequence is as follows:

Step 1. Prior to building, the proposed area should be deep tilled to a depth of 2 to 3 feet using a tractor and subsoiler with two deep shanks (curved metal bars) to create rips perpendicular to the direction of flow. (This step is usually omitted when compost is used for narrower filter strips.)

Step 2. A second deep tilling to a depth of 12 to 18 inches is needed after final building lots have been graded.

Step 3. It is important to have dry conditions at the site prior to incorporating compost.

Step 4. An acceptable compost mix is then incorporated into the soil using a roto-tiller or similar equipment at the volumetric rate of 1 part compost to 2 parts soil.

Step 5. The site should be leveled and seeds or sod used to establish a vigorous grass cover. Lime or irrigation may initially be needed to help the grass grow quickly.

Step 6. Areas of compost amendments exceeding 2500 square feet should employ simple erosion control measures, such as silt fence, to reduce the potential for erosion and trap sediment.

Construction Inspection. Construction inspection involves digging a test pit to verify the depth of amended soil and scarification. A rod penetrometer should be used to establish the depth of uncompacted soil at one location per 10,000 square feet.

D.5. Maintenance Criteria

Maintenance Agreements. When soil amendments are applied on private residential lots, homeowners will need to be educated on their routine maintenance needs, understand the long-term maintenance plan, and be subject to a deed restriction or other mechanism enforceable by the local stormwater program to ensure that infiltrating areas are not converted or disturbed. The mechanism should, ideally, grant authority for local agencies to access the property for inspection or corrective action. In addition, the GPS coordinates for all amended areas should be provided upon facility acceptance to ensure long term tracking.

A simple maintenance agreement should be provided if soil restoration is associated with more than 10,000 square feet of reforestation. A conservation easement or deed restriction, which also identifies a responsible party, may be required to make sure the newly developing forest cannot be cleared or developed management is accomplished (i.e., thinning, invasive plant removal, etc.). Soil amendments within a filter strip or grass channel should be located in a public right-of-way, or within a dedicated stormwater or drainage easement.

First Year Maintenance Operations. In order to ensure the success of soil amendments, the following tasks must be undertaken in the first year following soil restoration:

- *Initial inspections.* For the first six months following the incorporation of soil amendments, the site should be inspected at least once after each storm event that exceeds 1/2-inch of rainfall.
- *Spot Reseeding.* Inspectors should look for bare or eroding areas in the contributing drainage area or around the soil restoration area and make sure they are immediately stabilized with grass cover.

- *Fertilization.* Depending on the amended soils test, a one-time, spot fertilization may be needed in the fall after the first growing season to increase plant vigor.
- *Watering.* Water once every three days for the first month, and then weekly during the first year (April-October), depending on rainfall.

Ongoing Maintenance. There are no major on-going maintenance needs associated with soil amendments, although the owners may want to de-thatch the turf every few years to increase permeability. The owner should also be aware that there are maintenance tasks needed for filter strips, grass channels, and reforestation areas. An example maintenance inspection checklist for an area of Soil Amendments can be accessed in ***Appendix A.***

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APPENDIX E

TREATMENT VOLUME PEAK FLOW RATE

The peak rate of discharge for individual design storms is required for several different components of BMP design. While the primary design and sizing factor for most stormwater runoff reduction BMPs is the design Treatment Volume (*Tv*), several design elements will require a peak rate of discharge for specified design storms. The design and sizing of pretreatment cells, level spreaders, by-pass diversion structures, overflow riser structures, grass swales and water quality swale geometry, etc., all require a peak rate of discharge in order to ensure non-erosive conditions and flow capacity.

The peak rate of discharge from a drainage area can be calculated from any one of several calculation methods. The two most commonly used methods of computing peak discharges for peak runoff calculations and drainage system design are NRCS TR-55 Curve Number (CN) methods (NRCS TR-55, 1986) and the Rational Formula. The Rational Formula is highly sensitive to the time of concentration and rainfall intensity, and therefore should only be used with reliable Intensity-Duration-Frequency (IDF) curves or tables for the rainfall depth and region of interest (Claytor and Schueler, 1996). Unfortunately, there are no IDF curves available at this time for the 1” rainfall depth.

The NRCS CN methods are very useful for characterizing complex sub-watersheds and drainage areas and estimating the peak discharge from large storms (greater than two inches), but can significantly under estimate the discharge from small storm events (Claytor and Schueler, 1996). Since the Tv is based on a one-inch rainfall, this underestimation of peak discharge can lead to undersized diversion and overflow structures, resulting in a significant volume of the design Tv potentially bypassing the runoff reduction practice. Undersized overflow structures and outlet channels can cause erosion of the BMP conveyance features which can lead to costly and frequent maintenance, gnashing of teeth, and unacceptable levels of misery and despair.

Since IDF Curves may not be available for all the regions of West Virginia for the one-inch rainfall, and in order to maintain consistency and accuracy, the following Modified CN Method is recommended to calculate the peak discharge for the one-inch rain event. The method utilizes the Small Storm Hydrology Method (Pitt, 1994) and NRCS Graphical Peak Discharge Method (USDA 1986) to provide an adjusted curve number that is more reflective of the runoff volume from impervious areas within the drainage area. The design rainfall is a NRCS type II distribution so the method incorporates the peak rainfall intensities common in the eastern United States, and the time of concentration is computed using the method outlined in TR-55.

The following provides a step by step procedure for calculating the Treatment Volume peak rate of discharge (q_{pTv}):

Step 1: Calculate the adjusted curve number for the site or contributing drainage area.

The following equation is derived from the NRCS CN Method and is described in detail in the National Engineering Handbook Chapter 4: Hydrology (NEH-4), and NRCS TR-55 Chapter 2: Estimating Runoff:

$$CN = \frac{1000}{[10 + 5P + 10Q_a - 10(Q_a^2 + 1.25Q_aP)^{0.5}]}$$

Where:

CN = Adjusted curve number

P = Rainfall (inches), (1.0” in West Virginia)

Q_a = Runoff volume (watershed inches), equal to $Tv \div drainage\ area$

Note: When using hydraulic/hydrologic model for sizing a runoff reduction BMP or calculating the Tv peak discharge (q_{pTv}), designers must use this modified CN for the drainage area to generate runoff equal to the Tv for the one-inch rainfall event.

Step 2: Compute the site or drainage area Time of Concentration (Tc).

TR-55 Chapter 3: Time of Concentration and Travel Time provides a detailed procedure for computing the Tc.

Step 3: Calculate the Treatment Volume peak discharge (q_{pTv})

The q_{pTv} is computed using the following equation and the procedures outlined in TR-55, Chapter 4: Graphical Peak Discharge Method. Designers can also use WinTR-55 or an equivalent TR-55 spreadsheet to compute q_{pTv}:

- Read initial abstraction (I_a) from TR-55 Table 4.1 or calculate using $I_a = 200/CN - 2$

- Compute I_a/P (P = 1.0);
- Read the Unit Peak Discharge (q_u) from exhibit 4-II using Tc and I_a/P;
- Compute the QTv peak discharge:

$$q_{pTv} = q_u \times A \times Q_a$$

Where:

q_{pTv} = Treatment Volume peak discharge (cfs)

q_u = unit peak discharge (cfs/mi^2/in)

A = drainage area (mi^2)

Q_a = runoff volume (watershed inches = Tv/A)

This procedure is for computing the peak flow rate for the one-inch rainfall event. All other calculations of peak discharge from larger storm events for the design of drainage systems, culverts, etc., should use published curve numbers and computational procedures.

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Appendix F
BMP Landscaping & Plant Lists

General Landscaping Guidance

Vegetation is a crucial component of the Best Management Practices (BMPs) detailed in the Manual. Vegetation not only influences the beauty and aesthetic of the physical environment however it also performs a critical function in the performance of BMPs. Current research confirms the valuable role of plants, plant roots and soil in neutralizing, filtering, and taking up pollutants.

Thus it is important to select plants and plant communities which thrive and perform in various site conditions. Understanding the site's sun exposure, soil conditions, moisture conditions will inform the designer on the appropriate plant palette to use in particular BMPs. As mentioned previously, it is recommended that projects be designed by landscape architects and/or horticulturalists with knowledge of native plants, local sources of native plants, as well as experience in the design, installation and management of the BMPs.

Each site and each BMP require tailoring a planting plan to the various conditions, constraints and subtle nuances of topography, lighting, infiltration, drainage, and flood control strategies. The obvious design considerations are site context, site programming, microclimates, topography, irrigation potential, seasonal interest, and maintenance. The more delicate design considerations are extended ponding times, slight variations in planting zones, water velocity, habitat creation, and design controls which perform in extreme rain events. Yet another is the goal of achieving an aesthetic setting which may be "cultivated" versus "naturalistic."

Please see the individual BMP specifications in **Chapter 4** for more BMP-specific guidance on landscaping and plants.

Table F.1 is a list of nurseries that supply native plants within a multi-state area including and surrounding West Virginia.

Table F.2 is an extensive plant list for West Virginia that lists suitable plants in the following categories:

- Conservation Landscaping & General BMPs: Plants generally suitable to restore or enhance natural areas and buffer areas (e.g., see **Specifications 4.2.1.**

Sheetflow to Conservation Area and **4.1. Better Site Design Practices**) and for general landscaping of the area within and/or surrounding a BMP.

- Bioretention: Plants suitable for the various planting zones within Bioretention (see **Specification 4.2.3**).
- Regenerative Stormwater Conveyance (RSC): Plants particularly suited for this practice as part of a naturalistic drainage channel (see **Specification 4.2.7**).
- Stormwater Wetland: Plants suitable for the various depth zones within a stormwater wetland (see **Specification 4.2.11**).

The plants are grouped by: (1) trees, (2) shrubs, (3) perennials/annuals, (4) grasses and grass-like, and (5) ferns.

The table also lists the wetland indicator status and inundation tolerance for each plant as an aid in determining which plants are suitable for the wetter versus dryer areas of a BMP and its surroundings. For instance, "wetter footed" plants are more suitable for the bottom of a bioretention area, while plants that like a dryer setting are suitable for the edges and side slopes. The individual BMP specifications in **Chapter 4** contain more guidance on plant selections.

The table also notes the light preference for each plant (e.g., sun, partial shade, full shade).

Table F.1. Native Plant Nurseries in Proximity to West Virginia		
State	**Nursery Name**	**Nursery Web Site**
MD	American Native Plants **W**	www.amricannativeplantsonline.com
MD	Ayton State Tree Nursery	www.dnr.state.md.us/forests/nursery
MD	Chesapeake Natives. Inc.	www.chesapeakenatives.org
MD	Clear Ridge Nursery, Inc. **W**	www.clearridgenursery.com
MD	Environmental Concern **W**	www.wetland.org
MD	Lower Marlboro Nursery **W**	www.lowermarlboronursery.com
MD	Homestead Gardens	www.homesteadgardens.com
NJ/VA	Pinelands Nursery **W**	www.pinelandsnursery.com
PA	Appalachian Nursery	www.appnursery.com
PA	Octoraro Native Plant Nursery	www.OCTORARO.com
PA	Redbud Native Plant Nursery **W**	www.redbudnativeplantnursery.com
PA	New Moon Nursery, Inc. **W**	www.newmoonnursery.com
PA	North Creek Nurseries **W**	www.northcreeknurseries.com
PA	Sylva Native Nursery/Seed Co. **W**	www.sylvanative.com
VA	Lancaster Farms, Inc.	www.lancasterfarms.com
VA	Nature by Design **W**	www.nature-by-design.com
WV	Enchanter's Garden **W**	www.enchantersgarden.com
WV	Sunshine Farm & Gardens **W**	www.sunfarm.com

Notes:

This is a partial list of available nurseries and does NOT constitute an endorsement of them. For updated lists of native plant nurseries, consult the following sources:

West Virginia Native Plant Society www.wvnps.org
Virginia Native Plant Society www.vnps.org
Maryland Native Plant Society www.mdflora.org
Pennsylvania Native Plant Society www.pawildflowers.org
Delaware Native Plant Society www.delawarenativeplants.org

W: indicates that nursery has an inventory of emergent wetland species

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
TREES								
Acer negundo Box Elder	Sun	FAC+	Yes	Flood tolerant; Winter food source for birds & mammals	◆	◆		
Acer pennsylvanicum Striped Maple	Part Shade-Full Shade	FACU	No	Attractive flowers; High wildlife value	◆			
Acer rubrum Red Maple	Full Sun-Part Shade	FAC	Seasonal	Drought & flood tolerant; Attractive flowers (early spring) & fruit	◆	◆		◆
Acer saccharinum Silver Maple	Full Sun-Part Shade	FACW	Yes	Flood tolerant; Winter food source for birds & mammals		◆		◆
Acer saccharum Sugar Maple	All Light	FACU-	Moderate	Tolerates moisture; Maple syrup; High wildlife value; Fall color	◆			
Aesculus flava Yellow Buckeye	All Light	NI	Moderate	Tolerates moisture; Attractive flowers & fruit	◆			
Aesculus glabra Ohio Buckeye	All Light	FACU+	Moderate	Tolerates moisture; Attractive flowers & fruit	◆			
Alnus incana spp. Rugosa Speckled Alder	Full Sun-Part Shade	FACW+	Yes	Flood tolerant; Attractive flowers; Winter food source for birds		◆		◆
Amelanchier arborea Common Serviceberry	All Light	FAC-	Yes	Drought & flood tolerant; Attractive flowers; High wildlife value; Edible fruit (human)	◆	◆		
Amelanchier canadensis Shadblow, Serviceberry	All Light	FAC	Yes	Drought & flood tolerant; Winter food source for birds & mammals	◆	◆	◆	◆
Amelanchier laevis Allegheny Serviceberry	All Light	NI	Yes	Moderate flood tolerance; Drought intolerance; Attractive fruit; Fragrant flowers; Winter food source for birds; Edible fruit	◆	◆		
Aralia spinosa Devil's Walking Stick	Part Shade	FAC	No	Showy fruit – draws butterflies, bees, birds, deer; Aggressive	◆			◆

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Asimina triloba Pawpaw	Full Sun	FACU+	No	Flood tolerant; Attractive flowers; Food source for birds & mammals	◆			
Betula alleghaniensis Yellow Birch	Part Shade-Full Shade	FAC	Yes	Attractive peeling bark; Yellow fall color; High wildlife value; Prefers cool & moist environment	◆			
Betula lenta Sweet Birch	Full Sun-Part Shade	FACU	No	Attractive scaly bark; Aromatic; Golden yellow fall color; High wildlife value; Sap used to make birch beer	◆			
Betula nigra River Birch	Full Sun-Part Shade	FACW	Seasonal	Drought & flood tolerant; Attractive exfoliating bark; High wildlife value	◆	◆	◆	◆
Carpinus caroliniana Ironwood, Am Hornbeam	Part Shade-Full Shade	FAC	Moderate	Flood tolerant; Good fall color; Significant wildlife value	◆	◆	◆	◆
Carya alba Mockernut Hickory	Part Shade	NI	No	Bright yellow fall color; Edible nuts; Significant wildlife value; Host for moths	◆			
Carya cordiformis Bitternut Hickory	Full Sun-Part Shade	FACU+	Moderate	Flood tolerant; Yellow fall color; Significant wildlife value; Host for moths	◆	◆	◆	◆
Carya glabra Pignut Hickory	Full Sun-Part Shade	FACU-	No	Flood intolerant; Golden yellow fall color; Moderate wildlife value & host for moths	◆			
Carya ovata Shagbark Hickory	Full Sun-Part Shade	FACU-	Moderate	Moderate moisture; Attractive peeling bark; Moderate wildlife value; Edible nuts	◆			

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Celtis laevigata Sugarberry	Full Sun-Part Shade	FACW	Yes	Drought & flood tolerant; Significant food source for birds; Host for moths; Urban Tree	◆	◆	◆	◆
Celtis occidentalis Common Hackberry	All Light	FACU	Seasonal	Drought & flood tolerant; One of the best food & shelter plants for wildlife; Butterfly larvae host	◆	◆	◆	◆
Cercis canadensis Redbud	Full Sun-Part Shade	FACU-	No	Drought tolerant; Attractive flowers; Food source; Multi-stem	◆			
Chamaecyparis thyoides ** Atlantic White Cedar	Part Shade-Full Shade	OBL	Yes	Flood tolerant; Attractive berries; Evergreen		◆	◆	◆
Chionanthus virginicus Fringe Tree	Full Sun-Part Shade	FAC+	Yes	Flood tolerant; Attractive flowers; Food source for birds	◆	◆	◆	
Cornus alternifolia Pagoda Dogwood	Part Shade-Full Shade	NI	No	Attractive flowers; Very significant wildlife value	◆			
Cornus florida Flowering Dogwood	All Light	FACU-	Moderate	Attractive flowers; High wildlife value (migratory birds)	◆	◆		
Crataegus phaenopyrum Washington Hawthorn	Full Sun	FAC	Moderate	Attractive flowers; Significant wildlife value	◆	◆		
Crataegus crus-galli Cockspur Hawthorn	Full Sun-Part Shade	FACU	No	Attractive flowers; Significant wildlife value	◆			
Crataegus viridus Green Hawthorn	Full Sun-Part Shade	FACW	Moderate	Attractive flowers; Significant wildlife value	◆	◆	◆	◆
Diospyros virginiana Persimmon	Full Sun-Part Shade	FAC-	No	Flood & drought tolerant; Attractive flowers; High wildlife value; Edible fruit	◆			◆
Fagus grandifolia American Beech	Full Sun-Part Shade	FACU	Moderate	Flood & drought tolerant; High wildlife value; Attractive bark; Edible nuts	◆			

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Fraxinus americana White Ash	Full Sun-Part Shade	FACU	Moderate	Can be weedy; Flood & drought tolerant; Significant wildlife value	◆	◆		
Fraxinus pennsylvanica Green Ash	Full Sun-Part Shade	FACW	Moderate	Can be weedy; Flood & drought tolerant; Significant wildlife value	◆	◆	◆	◆
Ilex opaca American Holly	All Light	FACU+	Limited	Flood & drought tolerant; Winter food source for birds; Evergreen	◆	◆	◆	◆
Juniperus virginiana Eastern Red Cedar	Full Sun	FACU	No	Pollution tolerant; Significant food source for birds	◆		◆	◆
Liquidambar styraciflua Sweet Gum	Full Sun-Part Shade	FAC	Moderate	Significant food source	◆			◆
Liriodendron tulipifera Tulip Poplar	Full Sun-Part Shade	FACU	Moderate	Significant food source	◆			◆
Magnolia tripetala Umbrella Magnolia	Part Shade	FACU	No	Attractive flowers; Winter food source for birds	◆			
Magnolia virginiana ** Sweetbay Magnolia	Full Sun-Part Shade	FACW	Yes	Attractive flowers; High wildlife value; Evergreen	◆	◆	◆	
Nyssa sylvatica Black Gum	All Light	FACW+	Seasonal	Flood & drought tolerant; Attractive fall color	◆	◆	◆	◆
Pinus rigida Pitch Pine	Full Sun	FACU	No	High wildlife value; Evergreen	◆		◆	◆
Pinus taeda ** Loblolly Pine	Full Sun	FAC-	No	High wildlife value; Evergreen	◆		◆	◆
Platanus occidentalis American Sycamore	Full Sun	FACW-	Moderate	High wildlife value	◆			◆
Populus deltoides Eastern Cottonwood	Full Sun	FAC	Seasonal	Drought tolerant; High wildlife value	◆			
Prunus virginiana Chokecherry	Full Sun	FACU	No	Tolerates some salt; Can be maintained as hedge	◆			

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Quercus ssp Oak Family	All Light	NI	Seasonal	Quercus family provides significant wildlife value	◆	◆		
Quercus bicolor Swamp Oak	Full Sun-Part Shade	FACW+	Seasonal	Flood & drought tolerant; High wildlife value	◆	◆		◆
*Quercus michauxii*** Swamp Chestnut Oak	Full Sun	FACW+	Seasonal	High wildlife value	◆	◆		◆
Quercus palustris Pin Oak	Full Sun	FACW	Yes	Flood & drought tolerant; High wildlife value	◆	◆		◆
Sassafras albidum Sassafras	All Light	FACU-	No	Flood & drought tolerant; Attractive flowers; High wildlife value	◆			
*Taxodium distichum*** Bald Cypress	Full Sun-Part Shade	OBL	Yes	Flood tolerant; Food source for waterfowl		◆	◆	◆
SHRUBS								
*Aesculus pavia*** Red Buckeye	Full Sun-Part Shade	FAC	No	Flood and drought tolerant; Attractive flowers; Winter food source for birds	◆			
Alnus serrulata Hazel Alder	Full Sun-Part Shade	OBL	Yes	Attractive flowers; High wildlife value		◆	◆	◆
Calycanthus floridus Eastern Sweetshrub	All Light	NI	No	Flood & drought tolerant; Attractive flowers	◆			
Ceonanthus americanus New Jersey Tea	Part Shade–Full Shade	NI	No	Flood & drought tolerant; Attractive flowers	◆			
Cephalanthus occidentalis Buttonbush	All Light	OBL	Yes	Flood & drought tolerant; Attractive flowers; Significant wildlife value	◆	◆		◆
Castanea pumila Chinkapin	Part Shade	NI	No	Significant wildlife value	◆			

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Clethra alnifolia ** Sweet Pepperbush	Part Shade–Full Shade	FAC+	Yes	Very high wildlife value; Very fragrant	◆	◆	◆	◆
Comptonia peregrina Sweet Fern	Full Sun-Part Shade	NI	No	High wildlife value	◆			
Cornus alternafolia Alternateleaf Dogwood	Full Sun-Part Shade	NI	No	Flood tolerant; High wildlife value	◆			
Cornus amomum Silky Dogwood	Full Sun-Part Shade	FACW	Seasonal	High wildlife value	◆	◆		◆
Cornus racemosa Gray Dogwood	All Light	NI	No	Attractive flowers; High wildlife value	◆			◆
Cornus sericea Red Osier Dogwood	Full Sun-Part Shade	FACW+	No	Attractive flowers, fruit and stems	◆	◆		◆
Corylus Americana American Hazelnut	Full Sun – Part Shade	FACU-	No	Drought tolerant; Attractive flowers; Edible fruit	◆			
Euonymus americanus American Strawberry Bush	Part Shade–Full Shade	FAC	No	Flood & drought tolerant; Attractive berries; High wildlife value	◆			◆
Gaylussacia baccata Black Huckleberry	All Light	FACU	No	Flood & drought tolerant; Attractive flowers; High wildlife value	◆			
Gaylussacia dumosa Dwarf Huckleberry	All Light	FAC	No	Flood & drought tolerant; Attractive flowers; High wildlife value	◆			
Hamamelis virginiana Witchhazel	All Light	FAC-	No	Attractive flowers; Winter food source for birds & mammals	◆			
Hydrangea arborenscens Wild Hydrangea	Part Shade–Full Shade	FACU	No	Attractive flowers	◆			
Hypericaum densiflorum	Full Sun –	FAC+	No	Flood tolerant; Attractive flowers;	◆			

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Dense St. John's Wort	Part Shade			Semi-Evergreen				
Hypericaum prolificum Shrubby St. John's Wort	Part Shade–Full Shade	FACU	No	Flood & drought tolerant; Attractive flowers; Semi-Evergreen	◆			
Ilex glabra ** Inkberry	All Light	FACW-	Seasonal	Flood & drought tolerant; High wildlife value; Evergreen	◆	◆	◆	◆
Ilex laevigata ** Smooth Winterberry	Full Sun-Part Shade	OBL	Yes	Flood & drought tolerant; High wildlife value	◆	◆	◆	◆
Ilex verticilata Winterberry	All Light	FACW+	Seasonal	Flood & drought tolerant; High wildlife value	◆	◆		◆
Itea virginica ** Virginia Sweetspire	All Light	OBL	Yes	Flood & drought tolerant; High wildlife value	◆	◆		◆
Kalmia angustifolia Sheep Laurel	Part Shade–Full Shade	FAC	Moderate	Attractive flowers; Poisonous to hoofed browsers; Evergreen	◆			
Kalmia latifolia Mountain Laurel	Full Shade	FACU	Moderate	Attractive flowers; Poisonous to hoofed browsers; Evergreen	◆		◆	
Lindera benzoin Spicebush	All Light	FACW-	Yes	Flood & drought tolerant; High wildlife value; All parts edible	◆	◆		◆
Lyonia ligustrina Maleberry	Part Shade–Full Shade	FACW	Yes	Flood tolerant; Attractive flowers; Winter food source for birds	◆	◆		◆
*Morella pensylvanica*** Northern Bayberry	Full Sun – Part Shade	FAC	No	Flood & drought tolerant; Food source for birds; Evergreen	◆	◆	◆	◆
Photinia melanocarpa Black Chokeberry	Full Sun	FAC	No	Flood & drought tolerant; Attractive flowers; Significant wildlife value	◆			
Photinia pyrifolia Red Chokeberry	Full Sun	FACW	Yes	Flood & drought tolerant; Attractive flowers; Significant wildlife value	◆	◆		◆

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Physocarpus opulifolius Ninebark	Full Sun – Part Shade	FACW	Yes	Flood & drought tolerant; Attractive flowers; High wildlife value	◆	◆		
*Rhodo. Atlanticum*** Dwarf Azalea	Part Shade	FAC	No	Drought tolerant; Fragrant flowers; Food source for birds; Long lived	◆			
Rhodo. calendulaceum Flame Azalea	Full Sun – Part Shade	NI	No	Drought and flood tolerant; Fragrant flowers; Food source for birds	◆			
Rhodo. catawbiense Catawba Rosebay	Part Shade– Full Shade	NI	No	Attractive flowers; Evergreen	◆			
Rhodo. maximum Great Laurel	Part Shade– Full Shade	FAC	No	Flood & drought tolerant; Moderate food source; Evergreen	◆			
Rhodo. periclymenoides Pink Azalea	Part Shade– Full Shade	FAC	No	Flood & drought tolerant; Attractive flowers; Significant food source	◆			
Rhodo. prinophyllum Early Azalea	Part Shade– Full Shade	FAC	No	Flood & drought tolerant; Attractive flowers;	◆			
Rhodo. viscosum Swamp Azalea	Part Shade– Full Shade	OBL	Yes	Flood tolerant; Attractive flowers; Significant food source		◆	◆	◆
Rhus aromatic Fragrant Sumac	All Light	NI	No	Flood & drought tolerant; Attractive flowers & fall color; High wildlife value	◆	◆		
Sambucus nigra ssp. canadensis Elderberry	Full Sun	FACW	Yes	Flood & drought tolerant; Attractive flowers; High wildlife value	◆	◆		◆
Spiraea alba Meadowsweet	Full Sun – Part Shade	FACW+	Yes	Flood tolerant; Attractive flowers & stems; Significant wildlife	◆			◆

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
				value				
Spiraea tomentosa Steeplebush	Full Sun – Part Shade	FACW	Yes	Flood & drought tolerant; Attractive flowers; Significant wildlife value	◆			◆
Staphylea trifolia Bladdernut	Part Shade– Full Shade	FAC	No	Flood & drought tolerant; Significant food source for mammals	◆	◆		◆
Symphoricarpos orbiculatus Coralberry	All Light	UPL	No	Flood & drought tolerant; Attractive flowers; Winter food source for birds	◆			
Vaccinium angustifolium Lowbush Blueberry	Full Sun – Part Shade	FACU-	No	Drought tolerant; Attractive and edible fruit; High wildlife value	◆	◆	◆	◆
Vaccinium corymbosum Highbush Blueberry	Full Sun – Part Shade	FACW-	Yes	Drought & flood tolerant; Attractive and edible fruit; High wildlife value	◆	◆	◆	◆
Vaccinium macrocarpon Cranberry	Full Sun – Part Shade	OBL	Yes	Edible fruit; High wildlife value		◆	◆	◆
Viburnum acerifolium Mapleleaf Viburnum	All Light	UPL	No	Flood & drought tolerant; High wildlife value; Edible berries	◆			
Viburnum dentatum Arrowwood	All Light	FAC	No	Flood & drought tolerant; Attractive flowers; High wildlife value	◆			◆
Viburnum nudum Possumhaw Viburnum	All Light	OBL	Yes	Flood & drought tolerant; High wildlife value	◆	◆		◆
Viburnum prunifolium Blackhaw	Full Sun – Part Shade	FACU	No	Drought tolerant; High wildlife value; Edible berries	◆			
HERBACEOUS								
Aconitum uncinatum	Full Sun-	NI	No	Attractive flowers; Poisonous	◆			

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Southern Blue Monkshood	Shade							
Agave virginica (Manfreda virginica) False Aloe	Part Shade-Full Sun	NI	No	Attractive foliage	◆			
*Amsonia tabernaemontana*** Eastern Bluestar	Part Shade	FACW	Moderate	Attractive flowers	◆	◆		◆
Anemone virginiana Thimbleweed	Sun-Part Shade	NI	No	Attractive flowers	◆	◆		
Aquilegia canadensis Red Columbine	Part Sun-Shade	FAC	Yes	Attractive flowers; Attracts hummingbirds	◆	◆		
Aralia racemosa Spikenard	Full Sun-Shade	NI	Yes	Attractive flowers; Attractive fruit	◆			
Arisaema dracontium Green Dragon	Full Shade	FACW	Yes	Attractive bladed foliage			◆	◆
Arisaema triphyllum Jack-in-the-Pulpit	Part Sun-Shade	FACW-	Saturated	Attractive flowers; Attractive fruit			◆	◆
Asarum canadense Canadian Wild Ginger	Part Sun-Shade	NI	Yes	Attractive flowers	◆			
Asclepias incarnata Swamp Milkweed	Full Sun-Part Shade	OBL	Saturated	Drought tolerant		◆	◆	◆
Asclepias tuberosa Butterfly Weed	Full Sun	NI	No	Attractive flowers; Drought tolerant	◆	◆		
Aster novae-angliae New England Aster	Full Sun-Part Shade	FACW+	Yes	Attractive flowers; Drought tolerant	◆	◆		◆
Baptisia australis Blue False Indigo	Full Sun	NI	Moderate	Attractive flowers & fruit; Drought & flood tolerant	◆	◆		
Caltha palustris Marsh Marigold	Full Sun-Part Shade	OBL	Yes	Attractive flowers; Flood tolerant		◆	◆	◆

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Chelone glabra White Turtlehead	Full Sun-Part Shade	OBL	Saturated	Excellent growth; herbal uses		◆		◆
Chrysogonum virginianum Green and Gold	All Light	NI	Yes	Attractive flowers; Drought & flood tolerant	◆			
Conoclinium coelestinum Mist Flower	Full Sun-Part Shade	FAC	No	Attractive flowers; Drought tolerant	◆	◆		
Coreopsis auriculata Lobed Tickseed	Full Sun-Part Shade	NI	No	Attractive flowers; Drought tolerant; Evergreen	◆	◆		
Coreopsis lanceolata Lanceleaf Tickseed	Full Sun-Part Shade	FACU	No	Attractive flowers; Drought tolerant; Evergreen	◆	◆		
Coreopsis tinctoria Golden Tickseed (Annual)	Full Sun-Part Shade	FAC-	No	Attractive flowers; Drought tolerant; (Annual)	◆	◆		
Coreopsis verticillata Whirled Tickseed	Full Sun-Part Shade	NI	No	Attractive flowers; Drought tolerant; (Annual)	◆	◆		
Dicentra canadensis Squirrel Corn	Shade	NI	Yes	Attractive flowers	◆			
Delphinium exaltatum Tall Larkspur	Full Sun-Part Shade	NI	Yes	Attractive flowers; Flood tolerant	◆			
Echinacea purpurea Purple Coneflower	Full Sun-Part Shade	NI	No	Attractive flowers; Drought & flood tolerant	◆	◆		
Eupatoriadelphus fistulosus Joe Pye Weed	Full Sun-Part Shade	FACW	Saturated	Attractive flowers; Drought & flood tolerant		◆		
Eupatorium coelestinum Mist Flower	Full Sun-Part Shade	FAC	Yes	Attractive flowers; Drought & flood tolerant		◆		◆
Eupatorium dubium Joe Pye Weed	Full Sun-Part Shade	FACW	Yes	Attractive flowers; High wildlife value		◆		◆
Eupatorium perfoliatum Boneset	All Light	FACW+	Saturated	Attractive flowers; Flood tolerant		◆		◆

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Euphorbia corollata Flowering Spurge	Full Sun	NI	No	Attractive flowers; Drought tolerant	◆			
Eurybia divaricata White Wood Aster	Part Sun-Shade	NI	No	Attractive flowers; Drought tolerant	◆			
Filipendula rubra Queen of the Prairie	Part Sun-Shade	FACW	Yes	Attractive flowers; Flood tolerant		◆		◆
Gaultheria procumbens Eastern Teaberry	Part Sun-Shade	FACU	No	Attractive flowers & berries	◆			
Gentiana andrewsii Bottle Gentian	Part Sun-Shade	FACW	Yes	Attractive flowers; Drought & flood tolerant		◆		◆
Geranium maculatum Spotted Geranium	All Light	FACU	No	Attractive flowers; Flood tolerant; Semi-evergreen.	◆			
Helenium autumnale Sneezeweed	Full Sun	FACW+	Saturated	Attractive flowers; Flood tolerant		◆		◆
Helianthus angustifolius Swamp Sunflower	Full Sun	FACW	Yes	Attractive flowers; Drought & flood tolerant		◆		◆
Heuchera americana American Alumroot	All Light	FACU	No	Semi-Evergreen	◆			
Hibiscus moscheutos Red-Eyed Marsh Mallow	Full Sun	OBL	Yes	Attractive flowers; Flood tolerant		◆	◆	◆
Hydrastis canadensis Goldenseal	Part Sun-Shade	NI	No	Attractive flowers	◆			
Iris cristata Dwarf Crested Iris	All Light	OBL	Yes	Attractive flowers; Flood tolerant		◆	◆	◆
Iris virginica Virginia Iris	Full Sun-Part Shade	OBL	Yes	Attractive flowers; Flood tolerant		◆	◆	◆
Liatris spicata Dense Gayfeather	Full Sun	FAC+	No	Attractive flowers; Drought tolerant		◆		◆

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Liatris squarosa Blazing Star	Full Sun	NI	No	Attractive flowers; Drought tolerant		◆		◆
Lilium superbum Turk's-Cap Lily	Full Sun	FACW+	Yes	Attractive flowers; Flood tolerant				◆
Lobelia cardinalis Cardinal Flower	Full Sun- Part Shade	FACW+	Yes	Attractive flowers; Flood tolerant; Long Bloom Time		◆		◆
Lobelia siphilitica Great Blue Lobelia	Part Shade- Full Shade	FACW+	Yes	Blooms in late summer; bright blue flowers		◆		◆
Lupinis perennis Sundial Lupine	Part Shade- Full Shade	NI	No	Attractive flowers; Flood tolerant	◆			
Lysimachia terrestris Swamp Candles	Full Sun- Part Shade	OBL	Yes	Attractive flowers; Flood tolerant				◆
Meehania cordata Meehan's Mint	Part Shade- Shade	NI	No	Attractive flower; Semi-evergreen groundcover	◆			
Mertensia virginica Virginia Bluebells	Part Shade- Shade	FACW	Yes	Attractive flower; Flood tolerant	◆	◆	◆	◆
Mimulus ringens Monkeyflower	Full Sun- Part Shade	OBL	Yes	Attractive flower; Long summer bloomer		◆	◆	◆
Monarda didyma Beebalm	Full Sun- Part Shade	FAC+	Saturated	Attractive flower; Flood tolerant; Herbal uses	◆	◆		◆
Monarda fistulosa Wild Bergamot	Full Sun- Part Shade	FAC+	Yes	Attractive flower; Flood tolerant	◆	◆		
Nuphar lutea 'Advena' Yellow Pond Lilly	Full Sun- Part Shade	OBL	Yes	Attractive flower; High wildlife value		◆	◆	◆
Oenothera fruticosa Evening Primrose	All Light	FAC	No	Attractive flower	◆			
Orontium aquaticum Goldenclub	Full Sun	OBL	Yes	Attractive spike		◆	◆	◆

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Packera aurea (Senecio aureus) Golden Ragwort	All Light	FACW	Yes	Attractive flower; Flood tolerant	◆	◆		
Penstemon canescens Eastern Grey Beardtongue	Part Shade	NI	No	Attractive flower; Drought tolerant	◆			
Peltandra virginica Arrow Arum	Full Sun-Part Shade	OBL	Yes	Attractive flower; Food source for ducks				◆
Penstemon digitalis Beardtongue	Full Sun	FAC	No	Attractive flower; Drought & flood tolerant; Semi-Evergreen	◆	◆		
Penstemon laevigatus Eastern Smooth Beardtongue	Part Shade-Shade	FACU	No	Attractive flower; Drought & flood tolerant	◆			
Phlox davaricata Wild Blue Phlox	Part Shade-Shade	FACU	No	Attractive flower; Semi-Evergreen	◆	◆		
Phlox stolonifera Creeping Phlox	Part Shade-Shade	UPL	No	Attractive flower; Semi-Evergreen	◆	◆		
Physostegia virginiana Obedient Plant	All Light	FAC+	No	Attractive flower; Flood tolerant	◆	◆		
Polemonium reptans Jacob's Ladder	Part Shade-Shade	FACU	No	Attractive flower; Flood tolerant	◆	◆		
Pontederia cordata Pickerelweed	Full Sun	OBL	Yes	Attractive flower; Flood tolerant				◆
Porteranthus trifoliatus (Gillenia trifoliate) Bowman's Root	Full Sun-Part Shade	NI	No	Attractive flowers	◆			
Pycnanthemum incanum Hoary Mountainmint	Full Sun-Part Shade	FAC+	No	Attractive flowers	◆	◆		
Rhexia mariana Meadow-Beauty	Full Sun-Part Shade	OBL	Yes	Attractive flower; Flood tolerant		◆	◆	◆

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Rudbeckia fulgida Black-Eyed Susan	Full Sun-Part Shade	FAC	No	Attractive flower; Drought & flood tolerant	◆	◆		
Rudbeckia hirta Brown-Eyed Susan	Full Sun-Part Shade	FACU-	No	Attractive flower; Drought & flood tolerant (Annual)	◆	◆		◆
Sagittaria latifolia Duck Potato	Full Sun-Part Shade	OBL	Yes	Attractive flowers; Food source for many ducks				◆
Sanguinaria candadensis Bloodroot	Full Sun-Part Shade	NI	No	Attractive flowers early spring	◆			
Sanguisorba canadensis Canadian Burnet	Full Sun	FACW+	Yes	Attractive flower; Flood tolerant	◆	◆	◆	◆
Saururus cernuus Lizard's Tail	Full Sun-Part Shade	OBL	Yes	Attractive flower; Flood tolerant				◆
Scutellaria ovata Heartleaf Skullcap	Part Shade-Shade	NI	No	Attractive flower; Evergreen	◆			
Senna hebecarpa American Senna	Full Sun-Part Shade	FAC	Yes	Attractive flower; Drought & flood tolerant	◆	◆		
Sisyrinchium angustifolium Blue-Eyed Grass	Full Sun-Part Shade	FACW-	Yes	Attractive flower; Drought & flood tolerant	◆	◆	◆	◆
Solidago spp Goldenrod	Full Sun-Part Shade	FACU	No	Attractive flower; Drought & flood tolerant	◆	◆		
Solidago sempervirens ** Seaside Goldenrod	Full Sun-Part Shade	FACW	Yes	Dense & long blooming attractive flowers		◆		◆
Spigelia marilandica ** Woodland Pinkroot	Sun-Part Shade	NI	No	Attractive flowers; Colonizer	◆			
Spiranthes cernue Lady's Tresses	Full Sun-Part Shade	FACW	Yes	Attractive flower			◆	◆
Symphyotrichum laeve Smooth Blue Aster	Full Sun-Part Shade	NI	No	Attractive flower	◆	◆	◆	

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Symphyotrichum novae-angliae New England Aster	Full Sun-Part Shade	FACW-	No	Attractive flower; Drought & flood tolerant	◆	◆	◆	
Tiarella cordifolia Foam Flower	Part Shade-Shade	FAC-	No	Attractive flower; Semi-Evergreen	◆	◆		
Tradescantia virginiana Spiderwort	All Light	FACU	No	Attractive flower	◆	◆		
Verbena hastata Blue Vervain	Full Sun	FACW+	Yes	Attractive flowers		◆		◆
Vernonia noveboracensis Ironweed	Full Sun-Part Shade	FACW+	Yes	Attractive flower; Can be invasive		◆		◆
Veronicastrum virginicum Culver's Root	Full Sun-Part Shade	FACU	No	Attractive flower; Flood tolerant	◆	◆		
Viola labradorica Alpine Violet	Full Sun-Part Shade	FAC	No	Attractive flower	◆			
Waldstenia fragarioides Barren Strawberry	Full Sun-Part Shade	NI	No	Attractive flower; Groundcover	◆			
Zizia aurea Golden Zizia	Full Sun-Part Shade	FAC	No	Attractive flower; Drought & flood tolerant	◆			
GRASSES (or GRASS-LIKE)								
Andropogon gerardii Big Bluestem	Full Sun	FAC	Moderate	Forms clumps; Flood tolerant; Winter interest	◆	◆		
Andropogon virginicus Broom-Sedge	Full Sun	FACU	No	Attractive fall color; Drought and flood tolerant	◆	◆	◆	
Arundinaria gigantee Giant Cane	All Light	FACW	Yes	Attractive fruit; Drought and flood tolerant		◆	◆	◆
Carex crinita Fringed Sedge	All Light	OBL	Yes	Flood tolerant		◆	◆	◆

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Carex laxiculmis Spreading Sedge	All Light	NI	No	Evergreen; Spreads; Good groundcover	◆			
Carex lurida Shallow Sedge	All Light	OBL	Yes	Flood tolerant		◆	◆	◆
Carex stricta Tussock Sedge	All Light	OBL	Yes	Flood tolerant	◆	◆	◆	◆
Chasmanthium latifolium River Oats	All Light	FACU	No	Attractive fruit; Drought and flood tolerant	◆	◆	◆	◆
Dichanthelium clandestinum Deertongue	Full Sun	FAC+	No	Flood tolerant			◆	◆
Elymus riparius Riverbank Wild Rye	Part Shade-Full Shade	FACW	Yes	Flood tolerant		◆	◆	◆
Elymus virginicus Virginia Wild Rye	Part Shade-Full Shade	FACW-	No	Attractive fruit; Drought and flood tolerant; Adaptable		◆	◆	◆
Juncus effusus Soft Rush	Full Sun	FACW+	Yes	Flood tolerant		◆	◆	◆
Juncus torreyi Torrey's Rush	Full Sun	FACW	Yes	Flood tolerant				◆
Leersia oryzoides Rice Cutgrass	Full Sun-Part Shade	OBL	Yes	Flood tolerant; Good for stabilization & erosion control; Food source for birds				◆
Panicum virgatum Switch Grass	Full Sun	FAC	No	Attractive fruit; Drought and flood tolerant	◆	◆		◆
Scirpus atrovirens Green Bullrush	Full Sun	OBL	Yes	Food & cover for numerous bird species; High wildlife value				◆
Scirpus cyperinus Green Bullrush	Full Sun	FACW+	Yes	High wildlife value				◆
Scirpus pungens (formerly	Full Sun	FACW+	Yes	Food source for many species				◆

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
S. americanus) Common Threesquare								
Scirpus tabernaemontani (formerly S. validus) Soft Stem Bullrush	Full Sun	FACW+	Yes	Attractive flowers; Food source for many species				◆
Schizachyrium scoparium Little Bluestem	Full Sun	FACU-	No	Attractive fruit; Drought and flood tolerant; Tolerates poor soil conditions	◆	◆	◆	◆
Tridens flavus Purpletop Tridens	Full Sun	FACU	No	Attractive fruit; Drought tolerant	◆			
Tripsacum dactyloides Eastern Gammagrass	Full Sun	FACW	No	Attractive fruit; Flood tolerant; Evergreen			◆	◆
FERNS								
Adiantum pedatum Northern Maidenhair Fern	Full Shade-Part Sun	FAC-	Moderate	Colonizer; Herbal uses	◆			
Asplenium platyneuron Ebony Spleenwort	Part Shade-Full Shade	FACU	Moderate	Evergreen; Ground cover; Small fern	◆	◆	◆	◆
Asplenium rhizophyllum Walking Fern	Part Shade-Full Shade	NI	No	Ground cover; Small fern	◆			
Athyrium filix-femina Southern Lady Fern	Part Shade-Full Shade	FAC	Moderate	Flood tolerant	◆	◆	◆	◆
Dennstaedtia punctilobula Hayscented Fern	Part Shade-Full Shade	NI	No	Ground cover	◆			
Dryopteris intermedia Intermediate Fern	Part Shade-Full Shade	FACU	No	Ground cover	◆			
Dryopteris marginalis Marginal Woodfern	Part Shade-Full Shade	FACU-	Moderate	Evergreen; Ground cover	◆	◆		◆
Matteuccia struthiopteris	Part Shade-	FACW	Yes	Flood tolerant		◆		◆

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*
Ostrich Fern	Full Shade							
Onoclea sensibilis Sensitive Fern	Full Shade	FACW	Yes	Flood tolerant		◆		◆
Osmunda cinnamomea Cinnamon Fern	Part Shade-Full Shade	FACW	Yes	Flood tolerant		◆	◆	◆
Osmunda claytoniana Interrupted Fern	Full Sun-Full Shade	FAC	Moderate	Tolerates short term flooding; Low drought tolerance	◆	◆	◆	
Osmunda regalis Royal Fern	Full Sun-Full Shade	OBL	Saturated	Tolerates short term flooding; Drought tolerant	◆	◆	◆	◆
Polystichum acrostichoides Christmas Fern	Full Shade	FACU-	Moderate	Flood tolerant; Evergreen; Ground cover	◆	◆	◆	
Thelypteris noveboracensis New York Fern	Part Shade-Full Shade	FAC	Saturated	Drought and flood tolerant; Spreading ground cover	◆	◆		
Thelypteris palustris Marsh Fern	Full Sun-Part Shade	NI	Saturated	Flood tolerant; Spreading ground cover	◆			
Woodwardia areolata Netted Chain Fern	Part Shade-Full Shade	FACW+	Yes	Flood tolerant; Spreading ground cover		◆	◆	◆
Woodwardia virginica Virginia Chain Fern	Full Sun-Full Shade	u	Yes	Flood tolerant		◆	◆	◆

Wetland Indicator

** General Note: All of the plants with Wetland Indicators are found in wetland areas, however this chart marks those most suitable for high moisture conditions.*

[1]Notes: SOURCE: http://plants.usda.gov/wetland.html for West Virginia (Region 1)

UPL = Occurs in wetlands in another region, but occurs almost always (estimated probability 99%) under natural conditions in non-wetlands

FAC = Facultative, equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).

FACU = Facultative Upland, usually occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%).

Table F.2. Stormwater BMP Plant List

Plant	Light	Wetland Indicator[1]	Inundation Tolerance	Notes	Conservation & General BMP Landscaping	Bioretention	Regenerative Stormwater Conveyance	Stormwater Wetland*

FACW = FACW Facultative Wetland, usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.
OBL = Obligate Wetland, occurs almost always (estimated probability 99%) under natural conditions in wetlands.
NI = No Indicator; Or change in plant taxonomy. Insufficient information was available to determine an indicator status.
A positive (+) or negative (−) sign is used for the facultative categories. The (+) sign indicates a frequency towards the wetter end of the category (more frequently found in wetlands) and the (−) sign indicates a frequency towards the drier end of the category (less frequently found in wetlands).
Inundation Tolerance - Indicates the suitability of a plant based on the amount of moisture in the soil after a rain event:
No – Suitable in a site where water does not remain after a rain event (i.e., full sun, steep slope, sandy soil, windy area); Drought tolerant plants are suitable.
Moderate – Suitable in a site where soil remains damp or may remain saturated for a short time (i.e., full shade, bioretention areas; saturated soil for more than 24 hours);
Yes – Suitable in a site where soil remains saturated for most of the growing season (i.e., stormwater wetlands, bogs, swamps, pond edges, etc.)
Native to West Virginia
** - Non-Native to West Virginia. All plants are native to West Virginia unless indicated with a double asterisk.

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Appendix G
Resources for Design of Wet & Dry Ponds

The West Virginia Stormwater Management and Design Guidance Manual does not contain specifications for wet ponds and dry ponds (including extended detention ponds). This is because, while these ponds provide storage and peak rate control to meet local stormwater detention or flood control requirements, they do not provide substantial reductions for runoff volume on an average annual basis. Therefore, they are not advised as a stormwater BMP to meet the West Virginia MS4 permit requirement to reduce the first 1-inch of runoff.

Several other practices (e.g. stormwater wetlands, filtering devices) are also not known to reduce runoff volumes on an average annual basis, but are included in the Manual because of their pollutant removal capabilities. Therefore, these practices may be useful as part of a treatment train in watersheds that must account for pollutant reductions (for instance, to meet Total Maximum Daily Load requirements). It should be noted that wet pond design features can be incorporated into a stormwater wetland design. However, the specification (4.2.11) does not include the standard information on impounding structures and spillways.

Recognizing that wet and dry ponds may be useful or necessary in an overall stormwater design that must meet stormwater detention or flood control requirements, the following are design references for these ponds that are fairly recent and comprehensive.

West Virginia Erosion and Sediment Control Best Management Practice Manual (2006 – sediment basins and stormwater management ponds)
http://www.dep.wv.gov/WWE/PROGRAMS/STORMWATER/CSW/Pages/ESC_BMP.aspx

Virginia Stormwater BMP Clearinghouse (updated 2011)
http://vwrrc.vt.edu/swc/NonProprietaryBMPs.html

Maryland Stormwater Design Manual (2000; revised 2009)
http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/MarylandStormwaterDesignManual/Pages/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.aspx

Pennsylvania Stormwater Best Management Practices Manual (2006)
http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305

Note: State highway and drainage manuals would also provide good design resources.

Appendix H

Considerations for Impaired Waters

H.1. Description of TMDLs and the MS4 General Permit

Impaired waters are those that do not meet applicable water quality standards. Impaired waters are identified on the West Virginia Section 303(d) list until a Total Maximum Daily Load (TMDL) is developed and approved by U.S. EPA. A Total Maximum Daily Load (TMDL) is a plan of action used to clean up streams that are not meeting water quality standards. The plan includes pollution source identification and strategy development for contaminant source reduction or elimination. TMDLs are often referred to as "pollution diets" for the applicable pollutants of concern. In West Virginia, the TMDL program is part of the Watershed Branch.

Part III, Section D of the MS4 General Permit pertains to MS4s that discharge to impaired waters. These include: (1) 303(d) listed waters (waters listed as impaired, but for which a TMDL has yet to be developed), and (2) waters that have an approved TMDL. The General Permit specifies that the local stormwater management program must address the BMPs used to control the pollutants for which the waterbody is impaired, meet any wasteload allocation in a TMDL, and conduct monitoring (including modeling) to demonstrate the effectiveness of BMPs. A key phrase in the General Permit is that the stormwater management program should demonstrate that "there will be no increase of the pollutants of concern" (Part III, D, 1.a).

For information on how stormwater programs can address watershed specific TMDL issues see the U.S. EPA guidance titled: *Evaluating the effectiveness of municipal stormwater programs* and *Understanding Impaired Waters and Total Maximum Daily Load (TMDL) Requirements for Municipal Stormwater Programs.* Both of these guidance documents can be found on EPA's NPDES MS4 website: http://cfpub.epa.gov/npdes/stormwater/munic.cfm

Impaired waters and TMDLs may have significant implications for MS4s and local stormwater management programs. In the future, it may become incumbent on the local program to set up BMP tracking and accounting mechanisms in order to document the implementation of BMPs in accordance with the requirements of the West Virginia MS4 Permit, and to further evaluate the compliance with any TMDL's.

Table H.1 provides a quick summary of when an MS4 may be required to address stormwater pollutant sources associated with impaired waters and TMDLs.

Table H.1. Summary of Conditions Under Which MS4s Must Address TMDLs for Stormwater Sources
• The MS4 discharges into a waterbody that is impaired or has a TMDL and/or drains to a Chesapeake Bay tributary. • Urban stormwater (or urban sources) are listed as one of the sources of impairment that must be accounted for to implement the TMDL. • A wasteload allocation (or in some cases load allocation) has been assigned to the MS4, a group of MS4s, or perhaps to all permitted stormwater sources (e.g., all NPDES permits to include industrial, construction, municipal). The MS4 may have to participate in regional efforts to take an overall WLA and parse out individual MS4 responsibilities. • The specific MS4 permit has been updated (or will be updated) to include TMDL discharge requirements – these may be technology (BMP) driven or numeric.

H.2. Chesapeake Bay TMDL

The U.S. Environmental Protection Agency (EPA) has established the Chesapeake Bay TMDL, a comprehensive "pollution diet" that establishes Total Phosphorus, Total Nitrogen, and Sediment *Treatment Objectives* for the entire Bay watershed. Local *Watershed Implementation Plans* (WIPs) are being developed that address the "source sectors" of these pollutants: agriculture runoff, urban runoff, and wastewater treatment plant discharges, in the Bay watershed portions of West Virginia. The WIPs establish the criteria from which the *Performance Goals* for these objectives will be developed. More information on West Virginia's WIPs, and requirements for urban stormwater management in the Bay watershed portion of the state can be found at:

http://www.dep.wv.gov/WWE/watershed/wqmonitoring/Pages/ChesapeakeBay.aspx

West Virginia's Phase I Chesapeake Bay Watershed Implementation Plan (West Virginia WIP Development Team, 2010) describes the connection between the Chesapeake Bay TMDL and the one-inch performance standard in the MS4 General Permit:

> *Because the pre-development land uses already contribute non-negligible loads, it is reasonable to assume that the implementation of the one inch capture performance standard will, over time, reduce baseline conditions in MS4 areas of responsibility. Furthermore, the relatively higher delivery factors and development rates in those areas will counter growth in the non-regulated areas of the West Virginia portion of the Chesapeake Bay watershed. WVDEP believes that the MS4 requirements coupled with other BMPs implemented in non-regulated areas will be sufficient to attain no net increase in 2010 NA delivered nitrogen and phosphorous loads from urban stormwater sources. (p. 38)*

At this point in time, complying with the one-inch performance standard at new development and redevelopment sites will imply "no net increase" in associated pollutants in the context of the WIP.

Table H.2 provides the accepted nutrient and sediment annual load reduction capabilities of the BMPs provided in this manual. The *Total Reduction (TR)* column represents the total load reduction of the listed pollutants as the combined performance of Runoff Reduction (RR) and Pollutant Removal (PR). These values have been derived from compiled research and represent the latest available science on the ability of BMPs to manage annual volume and pollutant loads. (Hirschman et al. 2008).

The performance listed is contingent on the practice having been located, sized, and designed in accordance with the specifications provided in **Chapter 4**, and applied on new and redevelopment projects. The Total Reduction and Pollutant

Removal values listed in **Table H.2** are provided for informational purposes and may not be the same as the performance credits for nutrients and sediment assigned by the EPA Chesapeake Bay Program in its evaluation of BMPs for use in local WIPs.

> **Note:** *The Runoff Reduction credit provided in this manual is for purposes of "site-scale" new and redevelopment project compliance with the locally adopted WVMS4 Permit. Total Reduction and/or Pollutant Removal credit values are provided for informational purposes when considering a project's effect on a receiving stream with a TMDL load or waste load allocation. As such, compliance with the Chesapeake Bay TMDL and local WIPs is evaluated by the Chesapeake Bay Watershed Model through aggregation of BMPs at the watershed or sub-watershed scale, and are not evaluated using the same compliance tools.*

It is expected that stormwater treatment research will continue and new BMPs will be developed, as well as modifications to the design and runoff reduction credit of the existing BMPs provided in this manual. WVDEP will continue to evaluate the research and will also adopt a process for evaluating and implementing changes related to BMP design and performance. See Section 3.2.4 of **Chapter 3**.

It should also be noted that the EPA Chesapeake Bay Program will also be reviewing and potentially updating BMP design and performance standards for purposes of evaluating the effectiveness of the local WIPs. Given the variety of state stormwater programs in the Chesapeake Bay, it is expected that there may be differences in the state and/or local program criteria and that of EPA's Chesapeake Bay Model. WVDEP will continue to work with EPA through the permit cycles and where possible (or necessary) will consider permit or program guidance updates.

Table H.2. Comparative Load Reduction Capability of BMPs

Best Management Practice		RR[1] (%)	TP PR[2] (%)	TP TR[3] (%)	TN PR[2] (%)	TN TR[3] (%)	TSS PR[2] (%)	TSS TR[3] (%)	Bacteria TR[3] (%)	Metals TR[3] (%)	PAH's TR[3] (%)
Sheet Flow to Vegetated Filter Strips[4]	A/B Soils	50	0	50	0	50	50	75	20[5]		
	C/D Soils	25	0	25	0	25	50	63	20[5]		
	C/D Soils w/ compost amended soils (CA)	50	0	50	0	50	50	75	20[5]		
Sheet flow to Conservation Area[4]	A/B Soils	75	0	75	0	75	75	94	35[5]		
	C/D Soils	50	0	50	0	50	50	75	20[5]		
Simple Disconnection[4]	A/B Soils	50	0	50	0	50	50	75	NA		
	C/D Soils	25	0	25	0	25	50	63	NA		
	C/D Soils w/ CA	50	0	50	0	50	50	75	NA		
Simple Disconnection (alternative Practices)	Micro Infiltration	Refer to Infiltration									
	Residential Raingarden	Refer to Bioretention Level 1 and Level 2									
	Rainwater Harvesting	Refer to Rainwater Harvesting									
	Urban Planter	40	25	55	40	64	50	70	40		
Bioretention	Level 1	60	25	55	40	64	50	70	40		62
	Level 2	100[6] (80)	50	90	60	92	75	95	70		62
Permeable Pavement	Level 1	45	25	59	25	59	65	81	NA		
	Level 2	100[6] (75)	25	81	25	81	65	91	NA		
Grass Swale	A/B Soils	20	15	32	20	36	50	60	0	70[7]	62
	C/D Soils	10	15	24	20	28	30	37			
	C/D w/ CA	20	15	32	20	36	50	60			
Infiltration		100[6] (90)	25	93	15	92	50	95	40		
Regenerative Conveyance Channel[8]	A/B Soils	100[6] (80)	50	90	60	92	75	95	70		62
	C/D/Soils	60	25	55	40	64	50	70	40		
Rainwater Harvesting		90[9]	0	0[9]	0	0[9]	0	0[9]			
Vegetative Roof		100[6] (45)	0	45	0	45	50	70	NA		
Filtration Practices	Level 1	0	60	60	30	30	60	60	35[10]	69[7]	84
	Level 2	0	65	65	45	45	85	85	70[11]	69[7]	84
Stormwater Wetlands	Level 1	0	50	50	25	25	50	50	80[7]	42[7]	85
	Level 2	0	75	75	55	55	80	80	80	42[7]	85
Dry Ext Det	Level 1	0	15	15	10	10	50	50	30[10]		
	Level 2	15	15	28	10	24	70	75	60[10]		

Wet Pond	**Level 1**	**0**	**50**	**50**	**30**	**30**	**50**	**50**	**70**[7]	**62**[7]	
	Level 2	**0**	**75**	**50**	**40**	**40**	**80**	**80**	**70**	**62**[7]	

[1]Annual volume reduction based on managing the runoff from the 1" rain event (Hirschman et al., 2008)
[2] Pollutant removal by reducing the pollutant concentration (EMC) as it flows through the BMP.
[3]Total Pollutant Load Reduction as a function of combined **Runoff Reduction** (RR) and **Pollutant Removal** (PR).
[4] **Runoff Reduction** (RR) and **Total Reduction** (TR) values (%) are based on a ft^3 credit per ft^2 of BMP surface area (Refer to **Section 3.4** for details).
[5] Limited monitoring data. Estimates should be considered provisional
[6] Performance Credit for compliance with WV MS4 Permit; Actual Runoff Reduction values used for TR credit provided in parentheses.
[7] Median value from the CWP National Pollutant Removal Database
[8] New practice – performance credits comparable to bioretention/amended media filter. Credit is 100% of provided storage in step pools.
[9]Runoff Reduction credit is variable up to 90% - based upon storage and water usage budget.
[10]Median value from the International BMP Performance Database
[11]Q3 value from the International BMP Performance Database

References

Hirschman, D., Collins, K., and T. Schueler. 2008. *Technical Memorandum: The Runoff Reduction Method.* Center for Watershed Protection and Chesapeake Stormwater Network. Ellicott City, MD.

West Virginia WIP Development Team. 2010. *West Virginia's Chesapeake Bay TMDL Watershed Implementation Plan*. http://www.wvca.us/bay/documents.cfm