VOLUME 5

Low Impact Development

STORMWATER MANAGEMENT MANUAL

Prepared for

METROPOLITAN GOVERNMENT
NASHVILLE AND DAVIDSON COUNTY

2021

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Acknowledgement

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Chapter 1
INTRODUCTION

1.1 How to Use This Manual

This Volume presents an introduction to Low Impact Development (LID) design and specifically Green Infrastructure Practices (GIPs) which are characterized by their ability to reduce stormwater runoff volume through the use of infiltration, evapotranspiration, and/or rainwater reuse. It describes how LID designs should be selected, and contains a series of focused and concise fact sheets for each type of design. It is an addition to the Metropolitan Government of Nashville and Davidson County's (Metro's) Stormwater Management Manual (SWMM), which contains the following volumes:

Volume 1 – Regulations

Volume 2 – Procedures

Volume 3 – Theory

Volume 4 – Best Management Practices (BMP)

Volume 5 – Low Impact Development (LID) Design

Please see Volume 1 for information about site development, permitting procedures, and post-construction Stormwater Control Measure (SCM) requirements. SWMM Volume 5 contains the following four chapters:

Chapter 1 explains how to use this Manual, how it relates to the other volumes and why Metro is requiring LID.

Chapter 2 discusses principles of site layout, current incentives to promote the use of LID and an Operations and Maintenance overview.

Chapter 3 explains the methodology surrounding runoff reduction and how it shall be applied, including detailed guidance on design sizing and criteria.

Chapter 4 contains detailed specifications for each GIP.

When planning a site, this Manual may be best used in the order shown in **Figure 1**, below.

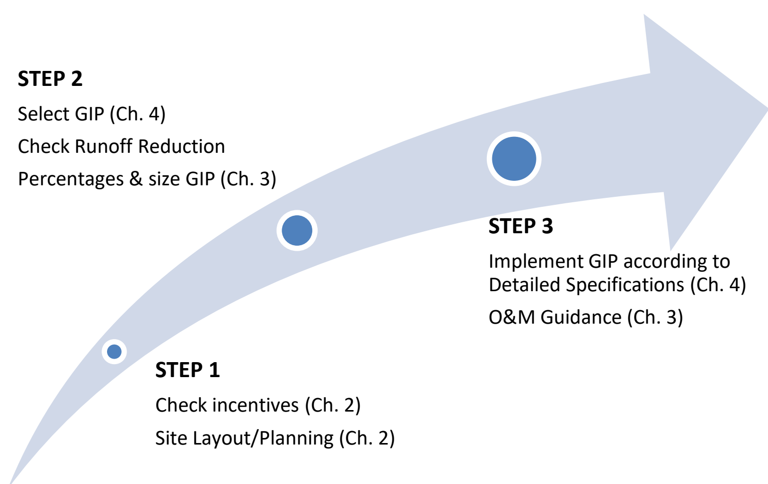


Figure 1 Site Planning Process

1.2 Why Green / Low Impact Development?

Current development patterns and traditional stormwater management techniques have resulted in large amounts of impervious surfaces in cities across the country – including Metro. Conventional development approaches to stormwater management often use practices to quickly and efficiently convey water away from developed areas. This results in larger volumes of runoff flowing directly to streams, rivers and combined sewer systems as well as any pollutants contained in the runoff.

In contrast, LID utilizes a system of source controls and small-scale, decentralized treatment practices to help maintain the hydrologic function of the landscape by allowing water to infiltrate, evapotranspirate or be reused onsite. The conservation of open space, the reduction of impervious surfaces, and the use of small-scale stormwater controls, such as green roofs, are just a few of the LID practices that can help maintain predevelopment conditions and keep greater volumes of runoff from routing to the stormwater system. Green Infrastructure Practices (GIP), as used in this Manual, is a term that refers to a subset of LID structural systems and practices that support the principles of LID and make use of volume-reducing designs and calculations.

LID techniques can offer many benefits:

<u>Municipalities</u>

- Protect flora and fauna
- Balance growth needs with environmental protection
- Installation of GIPs by private sector participation at residential, commercial, and industrial facilities
- Decrease flooding risks for small storms
- Create attractive natural and multifunctional public spaces

<u>Developers</u>

- Reduce land clearing and grading costs
- Potentially reduce infrastructure costs (streets, curbs, gutters, sidewalks)
- Reduce storm water management costs
- Increase lot and community marketability

<u>Environment</u>

- Preserve integrity of ecological and biological systems
- Protect site and regional water quality by reducing sediment, nutrient, and pollutant loads to water bodies
- Reduce impacts to terrestrial and aquatic plants and animals
- Preserve trees and natural vegetation
- Mitigate the heat island effect and reduce energy use

1.3 Brief Regulatory Background

As of 2016, Metro's National Pollutant Discharge Elimination System (NPDES) Phase I Municipal Separate Storm Sewer System (MS4) Permit requires that new development and significant redevelopment sites utilize GIPs for post development stormwater control where possible. The design requirement is to infiltrate, evapotranspire, or capture and reuse the first inch of rain preceded by 72 hours of no measureable rainfall. Metro Water Services (MWS) commissioned this Manual to encourage and incentivize LID design in Metro before its use became a requirement. The LID Manual was originally released in 2012, with minor revisions adopted in 2013. MWS has used the period since the Manual's release to test the methodology while the compliance path was voluntary. Where in its judgment strict application in a particular situation would conflict with sound engineering practice, Metro Water Services reserves the right to make exceptions to these regulations.

1.4 Stormwater Management Goals

GIPs are a set of land use and structural practices designed to reduce the volume of stormwater runoff from development through the use of the Runoff Reduction Method (RRM) employing runoff volume reducing approaches[1]. The overall goal of GIPs is to reduce stormwater runoff volume and to treat pollutant loads close to the source where they are generated. In doing so, GIPs provide many stormwater management benefits; such as improved water quality, flow management, groundwater recharge, and channel protection. GIPs minimize the hydrological impacts of urban development on the surrounding environment by intrinsically linking stormwater management to urban design and landscape architecture. This is accomplished with appropriate site planning and through the direction of stormwater towards small-scale systems dispersed throughout the site. These systems should be carefully selected based on the site's topographic and climatic conditions.

GIPs have numerous benefits and advantages over conventional stormwater management. The following benefits can be achieved by applying GIPs to new development, redevelopment, and capital improvement projects:

- **Provide volume control and pollutant removal**

  Under traditional flood-focused stormwater management, the importance of volume control from smaller storms and from the first flush of larger storms is overlooked. Reducing the amount of stormwater runoff, however, is one of the most effective stormwater pollution controls possible. GIPs help reduce runoff volume and decrease the amount of stormwater directly entering streams and sewer systems. In addition to reducing runoff volumes, individual GIPs can help address specific pollutant removal efficiencies through settling, filtration, adsorption, and biological uptake. By doing so, GIPs can help improve the receiving water's aquatic and terrestrial wildlife habitat and enhance recreational uses.

- **Recharge groundwater and stream base flows**

  Development tends to increase imperviousness, leading to increased direct runoff and reduced rainfall infiltration. Groundwater helps feed lakes and streams, and significant reductions or loss of groundwater recharge can reduce base flow in receiving waters, negatively impacting biological habitat and recreational opportunities. Many GIPs in Volume 5 infiltrate runoff, thus promoting ground water recharge.

- **Restore and protect stream channels**

  Channel erosion, on average, is estimated to account for most of the sediment load in urban watersheds and is a significant contributor to Total Suspended Solids (TSS) issues in middle Tennessee. GIPs can help protect or reduce stream channel degradation from accelerated erosion and sedimentation during and immediately after storm events by capturing stormwater volume and lowering stormwater peaks. By protecting stream channels, stream and riparian ecosystems have the potential to be improved and restored.

- **Address Combined Sewer Overflows**

  GIPs can be used to reduce stormwater inflows to combined sewer systems (CSS) that lead to overflows. Metro has approximately twelve square miles in the CSS area. Details of using green infrastructure in the CSS area are featured in Metro's Green Infrastructure Master Plan (MWS, 2009).

- **Provide ancillary environmental benefits**

  GIPs provide additional benefits, such as improved aesthetics through the use of attractive landscaping features (trees, shrubs, and flowering plants) which can increase property values. Other benefits include increased public awareness of stormwater management and water quality issues since practices are dispersed throughout a site and are typically more visible. GIPs such as green roofs, bioretention, and urban trees can help to mitigate the urban heat island effect and green roofs can also decrease the energy required to heat and cool buildings.

Chapter 2

PLANNING, DESIGN, INCENTIVES, AND OPERATIONS AND MAINTENANCE

2.1. Design Goals / Principles

Correctly pairing land uses with GIPs is an important first step in site planning. GIPs should be matched with land use and setting based on the criteria found in Chapter 4. For example, low density residential development lacks large parking areas conducive to pervious pavement with storage. However, bioretention may be especially good for residential use.

There are several important design goals and principals involved in incorporating GIPs:

- **Achieve multiple objectives**

  Stormwater management should be comprehensive and designed to achieve multiple stormwater objectives such as: managing peak flow and total volume; improving water quality; maintaining or improving the pre-development hydrologic characteristics; and maintaining water temperature. In some cases this requires multiple structural techniques; however, the objective of GIPs is to allow for less complex management systems to achieve multiple objectives.

- **Conserve natural features and resources**

  The conservation of natural features such as floodplains, soils, and vegetation helps to retain predevelopment hydrology functions, thus reducing runoff volumes. Impacts to natural features should be minimized by reducing the extent of construction and development practices that adversely impact predevelopment hydrology functions. This includes:
  - Avoiding mass clearing and grading, and limiting the clearing and grading of land to the minimum needed to construct the development and associated infrastructure
  - Leaving undisturbed stream buffers along both sides of natural streams, which is currently a Metro requirement
  - Preserving sensitive environmental areas, historically undisturbed vegetation, and native trees
  - Conforming to watershed, conservation, and open space plans
  - Designing development to fit the site terrain, and building roadways parallel to contour lines wherever possible
  - Clustering development and building upon the least porous soils or limiting construction activities to previously disturbed areas to preserve porous soils and natural slopes

- **Minimize soil compaction**

  Soil compaction disturbs native soil structure, reduces infiltration rates, and limits root growth and plant survivability. When protected, local soils can have a significant infiltration capacity, and can help meet design requirements. While soil compaction is necessary to provide structurally sound foundations, areas away from foundations are often excessively compacted by vehicle and foot traffic during construction. Minimizing soil compaction can be achieved by:
  - Reducing disturbance through design and construction practices
  - Limiting areas of access for heavy equipment
  - Avoiding extensive and unnecessary clearing and stockpiling of topsoil
  - Maintaining existing topsoil and/or using quality topsoil during construction

- **Manage stormwater close to the source**

  Redirecting runoff back into the ground, close to the point of origin, provides both environmental and economic benefits. Traditional stormwater systems, which collect and convey stormwater, generally increase flows and can suffer failures over time. GIPs are used to infiltrate stormwater into the ground instead of concentrating the flow and routing it offsite.

- **Reduce and disconnect impervious surfaces**

  Reducing and disconnecting impervious surfaces increases the rainfall that infiltrates into the ground. Impervious areas should be reduced by maximizing landscaping and using pervious pavements. In addition, the amount of impervious areas hydraulically connected to impervious conveyances (e.g., driveways, walkways, culverts, streets, or storm drains) should be reduced as much as possible. Examples include:
  - Installing green roofs
  - Directing roof downspouts to vegetated areas and GIPs
  - Using permeable pavements where permitted
  - Installing shared driveways that connect two or more homes or installing residential driveways with center vegetated strips
  - Allowing for shared parking in commercial areas
  - Encouraging building developers to increase their number of floors instead of their building's footprint

2.2. Incentives

Currently offered incentives for LID offered in Metro are shown in **Table 1**. Please visit MWS' Low Impact Development webpage to check for additional incentives.

Table 1. Green Infrastructure Incentives

Incentive	Requirement/Benefit
Stormwater User Fee Credit	Sites designed in accordance with the LID Manual can receive a downward adjustment in their Stormwater User Fees.
Redevelopment Credit	Certain previously developed sites can meet a Runoff Reduction goal of 60% instead of 80%. A site must have a current, pre-development runoff coefficient (Rv) greater than 0.4 to qualify.
Quantity Analysis (see Chapter 3.2.5.)	Volumetric GIPs can be utilized for water quantity in lieu of or in addition to traditional detention structures.

Certain GIPs will also help sites earn credits under the LEED certification system. Please consult the LEED Reference Guides for more information.

Chapter 3
THE RUNOFF REDUCTION METHOD

3.1 Introduction

The Runoff Reduction Method (RRM) serves as the basis for Metro's approach to GIP design. The basic RRM derivation can be found in original references.[1] Runoff volume reduction is the focus of this approach; and runoff reduction equals pollution reduction. Thus, understanding and calculating every aspect of a site's land condition in relation to runoff reduction is important. Using the RRM, every land surface can now have an assigned rating in terms of rainfall capture. For example, if open space can infiltrate a significant rainfall event, and it can be credited with 100% TSS removal for all the rainfall it infiltrates, then the open space itself becomes an effective control. Even impervious surfaces capture a small amount of water and therefore do not generate 100% runoff. An LID Site Design Tool has been created to aid engineers in designing the water quality treatment for a project in accordance with the methodology in the LID Manual. Please see MWS website for more information.

Site drainage areas that cannot meet the runoff reduction requirement due to site limitations must be designed for pollutant removal. Please see Section 7.2 of Volume 1 for more information on site limitations. This approach focuses mainly on engineered controls to reduce stormwater pollution as runoff flows through structural controls, and requires that they meet an 80% removal efficiency of Total Suspended Solids (TSS). Open space land use is of only minor importance.

3.1.1 Objectives

The basis for the RRM is a rainfall volume capture goal. In Metro the method was designed to fulfill several complimentary objectives:

- Meet the one-inch capture requirement under the NPDES MS4 Permit;
- Reflect local hydrologic and land conditions;
- Incentivize the use of natural solutions;
- Provide an approach that is simple and effective for the range of development projects occurring in Metro.

It was found that these objectives could be largely met through the use of a single overarching design standard, backed by specific volume-capture standards for structural controls and rainfall intensity scaled runoff coefficients for other land uses. To be eligible for approval of a site design under this approach the designer must lay out the site such that the total rainfall for a one-inch event of moderate intensity is captured and treated on site through a combination of infiltration, evapotranspiration, harvest and/or use. This objective is accomplished through site layout and GIP design.

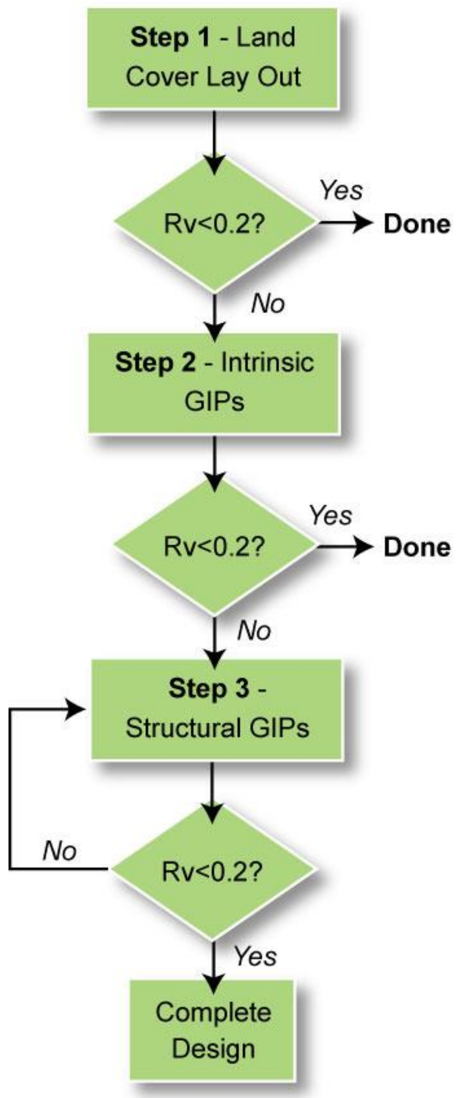
The first step in determining if the standard is met is to determine the volumetric runoff coefficient, Rv, which is the percentage of fallen precipitation that runs off of a specific land use area (See Equation 3.1). Rv within this method reflects a site's post-development runoff volume for storms in the one-inch or larger range. Based on national studies and standards, and supported by local rainfall-runoff analysis for Nashville soils, it was found that an Rv value of 0.20 generally indicates the capture of the first one-inch of rainfall. Storms larger than one inch may cause runoff.

Each land use is assigned an Rv value. Once Rv values have been developed, they must be weighted for the respective areas. If the weighted Rv for the whole site is 0.20 or less, the standard has been met. If the Rv standard has not been met, GIPs consisting of intrinsic designs and structural controls devised to capture the remaining required volume are added to the design. These effectively modify the Rv value for contributing drainage areas to that intrinsic design or control. These are shown in **Tables 2 and 3** in **Section 3.2**.

[1] Chesapeake Stormwater Network, CSN Tech. Bull. No. 4, "Technical Support for the Bay-Wide Runoff Reduction Method, Ver. 2.0", (undated). and Center for Watershed Protection, "Technical Memorandum: The Runoff Reduction Method" April 18th, 2008

3.1.2 Conceptual Steps in the Runoff Reduction Method

The RRM follows the steps shown below:



Step 1: Reduce Runoff Through Land Use and Ground Cover Decisions.
This step focuses on the "background" land cover and how much rainfall it removes from runoff. Design activities in Step 1 focus on impervious area minimization, reduced soil disturbance, forest preservation, etc. The goal is to minimize impervious cover and mass site grading and to maximize the retention of forest and vegetative cover, natural areas and undisturbed soils, especially those most conducive to landscape-scale infiltration.

Calculations for the RRM for Step 1 include the computation of volumetric runoff coefficients (Rv) for land use and Hydrologic Soil Group (HSG) combinations (including impervious cover). Site cover runoff coefficients are shown in **Table 2**.

Step 2: Apply Environmental Site Design Practices (Non-Structural GIPs).

If the target volume capture (Rv ≤ 0.20) has not been attained in Step 1 then Step 2 is required. This step focuses on implementing the more intrinsic GIPs during the early phases of site layout. In this step the designer enhances the ability of the background land cover to reduce runoff volume through the planned and engineered use of such practices as sheet flow, grass channel, and reforestation. Each of these practices is assigned an ability to reduce one-inch of rainfall in a storm of moderate intensity; and this assignment is conveniently captured in the Runoff Removal Credit or the RR Credit. RR Credit values for non-structural GIPs are shown in **Table 3**.

Step 3: Apply Structural GIPs.

If the target one-inch capture volume (Rv ≤ 0.20) has not been attained, Step 3 is required. In this step, the designer experiments with combinations of more structural GIPs on the site. In each case, the designer estimates the area to be treated by each GIP to incrementally meet the overall runoff reduction goal. Such engineered practices as infiltration trenches, bioretention, green roofs, permeable pavement, cisterns, etc. are envisioned. Design and sizing standards have been created for each of these GIPs to ensure their ability to meet the one-inch volume capture still required after Steps 1 and 2 have been analyzed. RR Credit values for structural GIPs are also shown in **Table 3**.

The guidance for the effectiveness of the various GIPs is expressed in terms of percent volume reduction (Runoff Reduction Credit).

At the end of Step 3, the designer must have achieved the required one-inch volume capture – which is accomplished by attaining an area weighted Rv value of 0.20 or less. The following sections describe how to calculate Rv and associated variables.

3.2 Technical Details

3.2.1 STEP 1: Land Use Rv Values

The volumetric runoff coefficient (Rv) is the ratio of the runoff divided by the target rainfall. If 45% of the rainfall for a range of storms in the one-inch range and larger is discharged from the site, the Rv value equals 0.45. Unlike a Rational Method C Factor, for example, Rv is not a constant individual storm-based value but is rainfall intensity and total depth dependent. Rv values could be developed for individual storms, seasons, or even on an annual basis. **Table 2** shows the Rv values derived for Metro to estimate runoff from larger storms of moderate intensity meeting the one-inch and greater standard.

Table 2. Site Cover Runoff Coefficients

Soil Condition	Volumetric Runoff Coefficient (Rv)			
Impervious Cover	0.95			
Hydrologic Soil Group	**A**	**B**	**C**	**D**
Forest Cover	0.02	0.03	0.04	0.05
Turf	0.15	0.18	0.20	0.23
Gravel	0.6	0.6	0.6	0.6

These values serve as the basis for Step 1 in application of the RRM. The development of an area-weighted estimate of the total site Rv value using site land uses.

$$\text{Weighted } R_V = [(R_{V1} * A_1) + (R_{v2} * A_2) + \cdots]/(A_1 + A_2 + \cdots) \qquad \textbf{Equation 3.1}$$

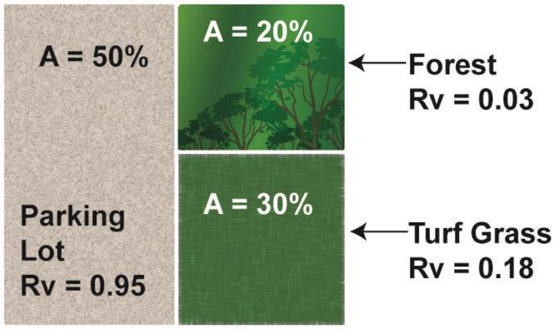


Figure 2 Site Example with Land Uses

Previously preserved areas or areas that cannot be developed should be excluded from the site Rv calculation. These areas may include, but are not limited to, water quality buffers, parkland, playgrounds, sport fields, floodway, preserved floodplain, and slopes $\geq$ 33%.

STEP 1 EXAMPLE

As shown in Figure 2, if we have a 10-acre site and 50% of the site was impervious, 20% forest, and 30% turf grass all over B Soils the Rv value would be:

$$\text{Site Weighted Rv} = [(5.0*0.95) + (2.0*0.03) + (3.0*0.18)]/10 = 0.54$$

That is, 54% of the rainfall for the larger design storms on the site runs off. This step does not consider the flow path of the runoff but simply the land use. The standard is the capture of the first inch and an Rv of 0.20 or less so additional GIPs must be planned and implemented.

3.2.2 STEPS 2 AND 3: Green Infrastructure Practice Rv Values

Steps 2 and 3 of the RRM involve the planning and design of Green Infrastructure Practices (both intrinsic and structural) to reduce the total site Rv to 0.20 or less. For impervious areas draining directly to the MS4 without passing through water quality or quantity controls, **MWS reserves the right to require treatment if a negative impact is perceived.** **Table 3** lists the acceptable GIPs and the assigned RR Credits for each, which corresponds with the values listed in each GIP specification. The two levels refer to specific design requirements contained in the specific GIP General Application sheets.

<table>
<tr><th colspan="9">Table 3. Green Infrastructure Practices Runoff Reduction Credit Percentages</th></tr>
<tr><th rowspan="2">Green Infrastructure Practice</th><th colspan="8">% Rainfall Volume Removed/Captured – RR Credit</th></tr>
<tr><th colspan="4">Level 1</th><th colspan="4">Level 2</th></tr>
<tr><td>1. Bioretention</td><td colspan="4">60</td><td colspan="4">80</td></tr>
<tr><td>2. Urban Bioretention</td><td colspan="4">40</td><td colspan="4">N/A</td></tr>
<tr><td>3. Permeable Pavement</td><td colspan="4">40</td><td colspan="4">80</td></tr>
<tr><td>4. Infiltration Trench</td><td colspan="4">50</td><td colspan="4">90</td></tr>
<tr><td>5. Water Quality Swale</td><td colspan="4">40</td><td colspan="4">60</td></tr>
<tr><td>6. Extended Detention</td><td colspan="4">15</td><td colspan="4">N/A</td></tr>
<tr><td>7. Grass Channel</td><td colspan="4">10/20*</td><td colspan="4">20/30*</td></tr>
<tr><td>8. Sheet Flow</td><td colspan="8">Design dependent: 50-75*</td></tr>
<tr><td>9. Reforestation (A, B, C, D soils)</td><td>96</td><td>94</td><td>92</td><td>90</td><td>98</td><td>97</td><td>96</td><td>95</td></tr>
<tr><td>10. Rain Tanks/Cisterns</td><td colspan="8">Design dependent: 0-99*</td></tr>
<tr><td>11. Green Roof</td><td colspan="8">Design dependent: 40-90*</td></tr>
</table>

* See GIP for additional information.

Note that the first six GIPs themselves occupy site land area. Because of their ability to absorb the rain that falls on them they are assigned the corresponding <u>Forest Cover</u> Rv values from **Table 2**. Other GIPs, where applicable, are assigned the <u>Turf</u> land cover Rv values from **Table 2**. The exception to this is Permeable Pavement (GIP-03), which is assigned the Rv values of 0.60 and 0.20 for Levels 1 and 2, respectively. Use of these values is <u>optional</u> and can be ignored for the first six GIPs if their area is less than ten percent of the total site area.

To calculate the Rv value for a Contributing Drainage Area (CDA) flowing through a GIP use Equation 3.2, below.

$$\text{GIP Rv} = \text{CDA } R_V(1 - \text{RR Credit})$$ **Equation 3.2**

GIP Rv equals the Contributing Drainage Area volumetric runoff coefficient as treated by the GIPs. CDA Rv is the weighted Rv value for the drainage area flowing to the GIPs. It should be weighted, using Equation 3.1, if the drainage area has multiple land uses. If the drainage area contains only one land use the CDA Rv value is the Rv for that single land use.

EXAMPLES

If part of the current site is impervious and has an Rv value of 0.95, it can be sent through a bioretention structure with Level 2 design (80% RR Credit) and the following reduction calculation would result:

GIP Rv = 0.95 *(1-0.80) = 0.19

Thus, the bioretention facility meeting the Level 2 design criteria would cause that impervious area to meet the standard of an Rv of 0.20 or less.

Level 1 Reforestation of a C soil would result in that land area changing from an Rv of 0.2 (See Table 2) to:

GIP Rv = 0.20 *(1-0.92) = 0.02

3.2.3 SPECIAL CASE: Rv Values for Controls in Series

The calculation of the volume removal rate for controls in series can be complex and specific GIP dependent. The upstream control has the benefit of initially handling runoff from the many small storms while the second control in series must handle the overflow from the first – a set of fewer and larger storms. Therefore, the ability to capture instantaneous volumes and store them for later removal is key for the downstream controls. In addition to cisterns, only the first six controls in **Table 3** can be used as the second GIP in a series volume removal calculation: bioretention, urban bioretention, permeable pavement, infiltration trench, water quality swale, and extended detention.

The following equation shall be used for calculation of the total Rv factor for GIPs in series:

$$\text{GIP } R_{V\ \text{SERIES}} = \text{CDA } R_V(1 - RR_1 \text{ Credit})(1 - RR_2 \text{ Credit})$$ **Equation 3.3**

Where CDA Rv is the volumetric runoff coefficient of the land cover flowing into the first GIP in the series (e.g. CDA Rv = 0.95 for impervious area). RR_1 Credit is the percent volume reduction credit for the first GIP in the series from **Table 3** and RR_2 is the percent volume reduction credit for the second (e.g. downstream) GIP in the series from **Table 3**. Credit will be granted for no more than two controls used in series.

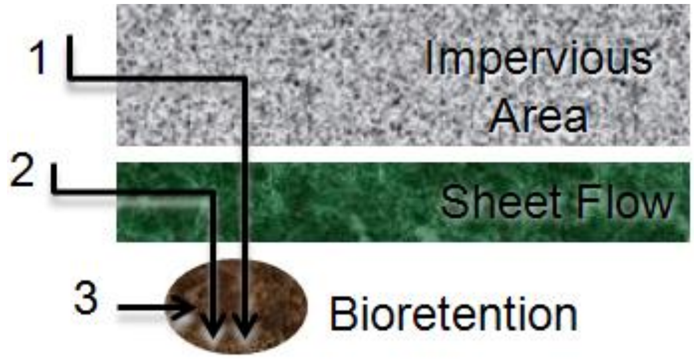


Figure 3 Series Credit Example

EXAMPLE

A 0.5-acre impervious area (IA) (Rv=0.95) is disconnected through a 0.25-acre C soil sheet flow area (Rv=0.20) and then enters a 0.06-acre Level 2 bioretention facility (Rv=0.04). See Figure 3 for schematic. The following calculation gives the Rv for that impervious area (note that the grassy area also has its own Rv value, and calculation (1) is only for the impervious area). Sheet flow is Level 1 (RR Credit 50%) while bioretention design is Level 2 (RR Credit 80%). Calculate the Rv for each of the three parts of the site – only the impervious area is demonstrating GIPs in series:

(1) IA through GIP $Rv_{SERIES} = 0.95*(1-0.50)(1-0.80) = 0.10$

(2) Sheet Flow GIP $Rv = 0.20*(1-0.80) = 0.04$

(3) Bioretention Rv (optional - Forest in C Soil) = 0.04

Site Rv for criteria attainment using Equation 3.1 is:

$$Rv_{FINAL} = (0.50*0.10 + 0.25*0.04 + 0.06*0.04)/(0.50+0.25+0.06) = 0.08$$

This equation says that 95% of the rainfall runs off the impervious area and enters the sheet flow area. 50% of that flow is captured in the sheet flow area. The remainder enters the bioretention facility (the largest storms) and 80% of that is captured by that GIP designed as a Level 2 facility allowing about 10% to overflow the facility in the design situation.

The Rv value for the whole site is 0.08, well ahead of the design requirement. Use of the bioretention area in the calculation is optional since its surface area is less than ten percent of the total site area.

3.2.4 Sizing of Media-Based GIPs

Standard practice in the sizing of media-based GIPs (bioretention, urban bioretention, permeable pavement, infiltration trenches and water quality swales) has been to assume that the runoff from a one-inch storm is instantaneously contained within the control, and that the control is completely dry prior to this. Through hourly rainfall simulation modeling using Metro rainfall, these offsetting assumptions, one conservative and one non-conservative, have been found to result in a design that approximates an 80% removal of runoff volume (Rv = 0.20) for all native soil infiltration rates. Underdrains are required for parent material infiltration rates less than or equal to 0.5 in/hr. As such the following guidance is provided for sizing these types of facilities. Details for each type are provided in the respective specification sections. Details for sizing cisterns are also located in the specific specifications.

Table 4 provides basic volume-based specifications for the standard recommended soil-based media and gravel. Soil-based media is used for GIPs: bioretention, water quality swales and urban bioretention. Gravel is used for design alternatives for the above listed GIPs, as well as, the storage layers for permeable pavement and infiltration trenches.

Field capacity of the soil is the amount of moisture typically held in the soil/gravel after any excess water from rain events has drained and varies greatly between soil-based media and gravel.

Table 4. Media Volume-Based Specifications		
Parameter	Value	
	Porosity	Field Capacity
Soil-Based Media[1]	0.25	0.25
Gravel[2]	0.40	0.04
Ponding	1.0	NA

1. Soil-Based Media GIPs - bioretention, water quality swales and tree planter boxes
2. Gravel GIPs - design alternatives for GIPs in 1, storage layers for permeable pavement and infiltration trenches

All media-based GIPs shall be sized to provide storage volume for the complete runoff from one inch of rain over the contributing drainage area (CDA). Thus, all media storage GIPs shall be sized using the following equations:

$$T_V = M(P)(CDA)(R_V)\left(\frac{43{,}560\ \text{ft}^2}{1\ \text{ac}}\right)\left(\frac{1\ \text{ft}}{12\ \text{in}}\right) = n(D)(SA)$$ **Equation 3.4**

Where:
Tv = GIP treatment volume in cubic feet; pretreatment volume is excluded from required treatment volume
CDA = the contributing drainage area in acres
M = Multiplier based on treatment level (included in the LID spreadsheet tool)
P = 1 inch
Rv = runoff coefficient for the CDA
SA = surface area in square feet of the GIP
D = media depth of GIP in feet.
n = Porosity
(D)(n) = D_E if more than one media type is required

To find the equivalent storage depth for media-based GIPs with multiple layers of media the equivalent storage depth must be calculated using the following equation:

$$\text{Equivalent Storage Depth} = D_E = n_1(D_1) + n_2(D_2) + \cdots$$ **Equation 3.5**

Where n_1 and D_1 are for the first layer, etc.

Note that the Rv value is for the total area draining to the control. So, if a filter strip is included in the area then a weighted Rv should be calculated but not a credit reduced Rv.

EXAMPLE

Using the previous example 0.5 acres of impervious area and 0.25 acres of grass enter the bioretention area. First calculate the volume design Rv for the CDA:

CDA Rv = (Rv1*A1 + Rv2*A2)/(A1+A2)= (0.95*0.50+0.20*0.25)/(0.50+0.25) = 0.70

The bioretention pond is Level 2 and thus will have 1.25*Tv for the volume, media depth of 36 inches and a maximum of 6 inches of ponding. The Equivalent Depth = (3 ft)(0.25) + (0.5 ft)(1.0) = 1.25 ft. Then by application of Equations 3.4 and 3.5, solving for SA:

Tv = 1.25*1"*0.75*0.70*43,560/12 = 2,382 cubic feet = SA*D_E = (SA)(1.25 ft)
SA of GIP = 1,906 Square Feet

3.2.5 Calculation of Curve Numbers with Volume Removed

The removal of volume by GIPs changes the runoff depth entering downstream stormwater quantity structures. An approximate approach to accounting for this in reducing the size of peak flow detention facilities is to calculate an "effective SCS curve number" (CNadj) which is less than the actual curve number (CN). CNadj can then be used in hydrologic calculations and in routing. The method can also be used for other hydrologic methods in which a reduction in runoff volume is possible.

Equation 3.6 provides a way to calculate a total runoff if the rainfall and curve number are known.

$$Q = \frac{(P-0.2\times S)^2}{(P+0.8\times S)} \quad \text{and} \quad S = \frac{1000}{CN} - 10$$ **Equation 3.6**

Equation 3.6 is the standard SCS rainfall-runoff equation where P is the inches of rainfall for the 24-hour design storm (See **Stormwater Management Manual, Volume 2**), and Q is the total runoff in depth for that storm in inches.

The adjusted total runoff in depth entering the flood control facility downstream of a GIP is calculated by taking the difference in the original total runoff in depth and the depth captured by the GIP (Tv from equation 3.4) expressed in watershed inches using equation 3.7 where CDA is the drainage area in acres for the subarea in question.

$$Q_{adj} = Q - \frac{12 * T_v}{43560 * CDA}$$ **Equation 3.7**

Equation 3.8 provides a method to calculate the modified curve number once the Qadj is found.

$$CN_{adj} = \frac{1000}{10 + 5P + 10Q_{adj} - 10\left({Q_{adj}}^2 + 1.25Q_{adj}P\right)^{1/2}}$$ **Equation 3.8**

The steps in calculating an adjusted Curve Number (CNadj) are:

Step 1. **Calculate Total Runoff for Storm (Q)** Chose the design return period, and using that rainfall as P, calculate an initial Q using Equation 3.6 and the calculated site curve number.

Step 2. **Calculate GIP Capture Volume (Tv)** Compute the captured volume in the GIP control using Equation 3.4 or proven cistern volume assuming a 72-hour inter-event dry period since the last cistern filling event.

Step 3. **Calculate Adjusted Total Runoff (Qadj)** As shown in Equation 3.7, subtract Tv expressed in watershed inches from Q computed in Step 1.

Step 4. **Calculate Adjusted Curve Number (CNadj)** Using Qadj and the P corresponding to the return period in question (the P from step 1), calculate the adjusted CN from Equation 3.8.

Step 5. Use CNadj in routing calculations for the specific return period in question.

The LID spreadsheet tool can be used to calculate the CNadj. The example on the next page illustrates this procedure using manual calculations.

EXAMPLE

A 1.5-acre parking lot is to drain into a larger site detention pond for the 2-year through 100-year storm. We wish to determine the curve number taking into account a bioretention basin at the downstream end of the parking lot and therefore need to calculate a modified curve number for the parking lot. The developed curve number is 98 for the parking lot.

Step 1. Using Equation 3.6 for a P = 7.53, the calculated Q = 7.30 inches.

$$Q = 7.30 = \frac{(7.53 - 0.2 * 0.20)^2}{(7.53 + 0.8 * 0.20)} \quad \text{and} \quad S = 0.20 = \frac{1000}{98} - 10$$

Step 2. We find Tv through sizing a Level 1 bioretention facility:

$$T_v = 1.5 * 0.95 * \frac{43{,}560}{12} = 5{,}173\text{ft}^3$$

Step 3. Over 1.5 acres the depth, in inches, removed is:

$$Q_{removed} = 0.95 \text{ in} = \frac{(5173\text{ft}^3)(12)}{43{,}560(1.5\text{ac})}$$

Step 3 cont. Qadj is:

$$Q_{adj} = 6.35 \text{ in} = 7.30 - 0.95$$

Step 4. Using Qadj and the 100-year P in Equation 3.8 we obtain the adjusted curve number of 90. We can check our work by substituting this CN back into Equation 3.6 to obtain the Q of Step 3.

$$CN_{adj} = 90 = \frac{1000}{10 + 5(7.53\text{in}) + 10(6.35\text{in}) - 10[(6.35\text{in})^2 + 1.25(6.35\text{in})(7.53\text{in})]^{1/2}}$$

Chapter 4
GREEN INFRASTRUCTURE PRACTICES

4.1 Overview

Communities are increasingly moving towards green infrastructure practices – or a combination of green and conventional stormwater management practices – to manage stormwater. Green infrastructure systems are an innovative approach to urban stormwater management that do not rely on the conventional end-of-pipe structural methods. Rather, they are an ecosystem-based approach that strategically integrates stormwater controls throughout an urban landscape to attempt to maintain a site's pre-development conditions. Targeted community or watershed goals and objectives are addressed through the use of structural and non-structural techniques such as permeable pavement, bioretention, cisterns, and public outreach.

Green Infrastructure Practices (GIPs) are intended to mimic the natural hydrologic condition and allow stormwater to infiltrate into the ground, evapotranspirate into the air, or be captured for reuse. Typical GIPs include: sheet flow, infiltration practices, permeable pavement, cisterns, bioretention, reforestation, green roofs, etc.

These GIPs are designed to meet multiple stormwater management objectives, including reductions in runoff volume, peak flow rate reductions, and water quality protection. Multiple small, localized controls may be combined into a "treatment train" to provide comprehensive stormwater management. The GIPs in this section have been designed to be integrated into many common urban land uses on both public and private property, and may be constructed individually, or as part of larger construction projects. Decentralized management strategies are encouraged to be tailored to individual sites; which can eliminate the need for large-scale, capital-intensive centralized controls; and may improve the water quality in Metro's streams and reduce the number of combined sewer overflows.

Table 5 and **Table 6** are included to facilitate selection of the most appropriate GIPs for a given situation. The following chapters provide a brief introduction to each practice, details on performance, suitability, limitations, and maintenance requirements.

Table 5. Effectiveness of SCMs in Meeting Stormwater Management Objectives

Practices	Volume	Peak Discharge	Water Quality
Bioretention	□	□	□
Urban Bioretention	□	□	□
Permeable Pavement	□	□	□
Infiltration Trench	□	□	□
Water Quality Swales (Dry)	□	□	□
Extended Detention	□	□	□
Grass Channels	□	□	□
Sheet Flow	□	□	□
Reforestation	□	□	□
Cisterns*	□	□	□
Green Roofs	□	□	□

* A single cistern typically provides greater volume reduction than a single rain tank.

Key: □ High effectiveness □ Medium effectiveness □ Low effectiveness

Rankings are qualitative. "High effectiveness" means that one of the GIP's primary functions is to meet the objective. "Medium effectiveness" means that a GIP can partially meet the objective but should be used in conjunction with other SCMs. "Low effectiveness" means that the GIP's contribution to the objective is a byproduct of its other functions, and another decentralized control should be used if that objective is important.

Table 6. Green Stormwater Infrastructure Land Use and Land Area Selection Matrix								
Practices	Criteria							
	Land Use							Land Area Required
	Schools	Com.	Indust.	SF Res.	MF Res.	Parks/Open Space	Roads/ Roadside	
Bioretention	□	□		□	□	□	□	□
Urban Bioretention	□	□			□	□	□	□
Permeable Pavement	□	□	□	□	□	□	□	□
Infiltration Trench	□	□		□	□	□	□	□
Water Quality Swales (Dry)	□	□			□		□	□
Extended Detention	□	□	□		□		□	□
Grass Channels	□	□		□	□	□	□	□
Sheet Flow	□	□		□	□	□	□	□
Reforestation	□		□	□	□	□	□	□ /□
Cisterns	□	□	□	□	□			□
Green Roofs	□	□	□		□			□

□ - Well suited for land use applications or high relative dedicated land area required.
□ - Average suitability for land use applications or moderate relative dedicated land area required.
□ - Low relative dedicated land area required.
Blank – Not applicable for land use.

References

Chesapeake Stormwater Network, CSN Tech. Bull. No. 4, "Technical Support for the Bay-Wide Runoff Reduction Method, Ver. 2.0", (undated). and Center for Watershed Protection, "Technical Memorandum: The Runoff Reduction Method" April 18th, 2008

National Association of Homebuilders Research Center. (No date).Municipal Guide to Low Impact Development.

Metro Water Services. 2009. The Metropolitan Government of Nashville and Davidson County Green Infrastructure Master Plan.

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Bioretention

Description: Bioretention cells are vegetated, shallow depressions. Captured runoff is treated by filtration through an engineered soil medium and is either infiltrated into the subsoil or exfiltrated through an underdrain.

Advantages/Benefits:

- Reduced runoff volume
- Reduced peak discharge rate
- Reduced Total Suspended Solids (TSS)
- Reduced pollutant loading
- Reduced runoff temperature
- Groundwater recharge (if soils are sufficiently permeable)
- Habitat creation
- Enhanced site aesthetics
- Reduced heat island effect

Disadvantages/Limitations:

- Problems with installation can lead to failure
- Minimum 2-foot separation from groundwater and bedrock is required
- Geotechnical testing required

Selection Criteria:

60% – 80% Runoff Reduction Credit

Land Use Considerations:

- [x] **Residential**
- [x] **Commercial**
- [x] **Industrial**

Maintenance:

- Regular maintenance of landscaping to maintain healthy vegetative cover
- Irrigation when necessary during first growing season
- Periodic trash removal

[M] **Maintenance Burden**
L = Low M = Moderate H = High

SECTION 1: DESCRIPTION

Bioretention Basins are structures treating parking lots and/or commercial rooftops, usually in commercial or institutional areas. Throughout this GIP bioretention basins are simply referred to as Bioretention. Inflow can be either sheet flow or concentrated flow. Bioretention basins may also be distributed throughout a residential subdivision, but they should be located in common areas and within drainage easements, to treat a combination of roadway and lot runoff.

The major design goal for bioretention is to maximize runoff volume reduction and pollutant removal. To this end, designers may choose to go with the baseline design (Level 1) or choose an enhanced design (Level 2) that maximizes pollutant and runoff reduction. If soil conditions require an underdrain, bioretention areas can still qualify for the Level 2 design if they contain a stone storage layer beneath the invert of the underdrain. **Table 1.2** outlines the Level 1 and 2 bioretention design guidelines. Local simulation modeling supports these runoff reduction credits for the mentioned contributing drainage area (CDA) to surface area ratios.

Figure 1.1. A typical bioretention basin treating a parking lot

SECTION 2: PERFORMANCE

The overall runoff reduction capabilities of bioretention in terms of the Runoff Reduction Method are summarized in **Table 1.1**. Bioretention creates a good environment for runoff reduction, filtration, biological uptake, and microbial activity, and provides high pollutant removal. Bioretention can become an attractive landscaping feature with high amenity value and community acceptance.

Table 1.1. Runoff Volume Reduction Provided by Bioretention Basins		
Stormwater Function	**Level 1 Design**	**Level 2 Design**
Runoff Volume Reduction (RR)	60%	80%
Treatment Volume (Tv) Multiplier*	1.10	1.25

*Incorporated into LID Site Design Tool calculations
Sources: CSN (2008) and CWP (2007)

SECTION 3: TYPICAL DETAILS

See Appendix 1-B and 1-C for required standard notes and applicable details for use in construction plans.

SECTION 4: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Bioretention can be applied in most soils or topography, since runoff simply percolates through an engineered soil bed and can be returned to the stormwater system if the infiltration rate of the underlying soils is low. Key considerations with bioretention include the following:

Infiltration/Soils. Infiltration is a key component of Low Impact Development (LID) design. Infiltration testing shall be required for all bioretention locations (see **Section 5.1**). Soil conditions do not constrain the use of bioretention but can affect the design requirements. Hydrologic Soil Groups (HSG) should be determined from NRCS soil data. For more information on soil types go to: http://websoilsurvey.nrcs.usda.gov/app/. Alternative HSG classifications will be considered when supporting reports from a licensed soil scientist or geotechnical engineer are provided.

Available Space. Planners and designers can assess the feasibility of using bioretention facilities based on a simple relationship between the contributing drainage area and the corresponding required surface area. The bioretention surface area will be approximately 3% to 10% of the contributing drainage area, depending on the imperviousness of the contributing drainage area (CDA), the subsoil infiltration rate, and the desired bioretention design level. The minimum length and width dimension of the bioretention area shall be 10 feet.

Accessibility. Bioretention facilities require periodic maintenance and must be accessible to various types of equipment. A path of travel for equipment no less than ten feet in width with a maximum slope of 3:1 must be provided for the bioretention facility. The path of travel shall be along no less than 50% of the perimeter of the bioretention area and must be accessible by common equipment and vehicles at all times. MWS staff can consider alternate access paths.

Elevation Considerations. Bioretention is best applied when the grade of contributing slopes is greater than 1% and less than 5%. Terracing or other inlet controls may be used to slow runoff velocities entering the facility. 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).

Subsurface Constraints. Vertical constraints such as retaining walls, structures, or other impermeable barriers are limited to a maximum of 50% of the bioretention perimeter (>50% see **GIP-02**). Vertical constraints are not permitted on the down gradient side of a bioretention area. Subsurface constraints five feet from the bioretention media will not count under this section. Bioretention subgrade shall always be separated from the water table and bedrock. Groundwater intersecting the filter bed 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 and/or bedrock.

Utilities. Designers must ensure that future tree canopy growth in the bioretention area will not interfere with existing overhead public utility lines. Public underground utilities and associated easements shall not be located within the bioretention footprint. Local utility design guidance shall be consulted in order to determine clearances required between stormwater infrastructure and other dry and wet utility lines. Private utilities should not be located within the bioretention area when possible.

Contributing Drainage Area. Bioretention works best with smaller contributing drainage areas, where it is easier to achieve flow distribution over the filter bed without experiencing erosive velocities and excessive ponding times. The maximum amount of impervious cover contributing to a bioretention should be a maximum of 5 acres. The maximum amount of impervious cover per outfall into a bioretention should be a maximum of 2.5 acres. Contributing drainage areas to bioretention areas shall be clearly conveyed in the construction plans.

Hotspot Land Uses. Runoff from hotspot land uses should not be treated with infiltrating bioretention without appropriate pretreatment and MWS staff approval. For additional information on stormwater hotspots, please consult **Section 6.3**.

Floodplains. Bioretention areas shall be constructed outside the limits of the 100-year floodplain. Flood waters from the 100-year event or smaller shall be prohibited from entering the bioretention underdrain or overflow system.

No Irrigation or Baseflow. The planned bioretention area shall not receive baseflow, irrigation water, chlorinated wash-water or other such non-stormwater flows, except for irrigation as necessary during the first growing season for the survival of plantings within the bioretention area (see **Section 9.2**).

Setbacks. It is not recommended to place bioretention areas immediately adjacent to structures. To avoid the risk of seepage, a licensed professional engineer should be consulted to determine the appropriate setbacks necessary to prevent bioretention infiltration from compromising structural foundations or pavement. At a minimum, bioretention basins should be located a horizontal distance of 100 feet from any water supply well and 50 feet from septic systems.

Applications. Bioretention has been used at commercial, institutional and residential sites in spaces that are traditionally pervious and landscaped. It should be noted that special care must be taken to provide adequate pretreatment for bioretention cells in space-constrained high traffic areas. Typical locations for bioretention could include parking lot features, courtyards, and unused pervious areas on a site.

SECTION 5: DESIGN CRITERIA

5.1 Soil Infiltration Rate Testing

One must measure the infiltration rate of subsoils at the subgrade elevation of the bioretention area. If the infiltration rate exceeds 0.5 inch per hour, an underdrain should not be utilized. If the infiltration rate of subsoils is greater than 0.1 inch per hour and less than or equal to 0.5 inch per hour, underdrains will be required. If the infiltration rate is 0.1 inch per hour or less bioretention should not be used. On-site soil infiltration rate testing procedures are outlined in **Appendix 1-A**. The number of soil tests varies base on the size of the bioretention area:

- < 1,000 ft^2 = 2 tests
- 1,000 – 10,000 ft^2 = 4 tests
- >10,000 ft^2 = 4 tests + 1 test for every additional 5,000 ft^2

A separation distance of 2 feet is required between the bottom of the excavated bioretention area and the seasonally high ground water table and/or bedrock.

For sites with large amounts of cut or fill it may not be practical to perform infiltration testing prior to grading the site. In these cases, a mass grading permit will be required.

MWS staff may work with design engineers to evaluate infiltrative testing alternatives when extreme site limitations exist.

5.2 Sizing of Bioretention Practices

5.2.1 Stormwater Quality

Sizing of the surface area (SA) for bioretention practices is based on the computed Treatment Volume (T_v) of the contributing drainage area and the storage provided in the facility. The required surface area (in square feet) is computed as the Treatment Volume (in cubic feet) divided by the equivalent storage depth (in feet). The minimum length and width dimension shall be 10 feet. The equivalent storage depth is computed as the depth of media, gravel, and surface ponding (in feet) multiplied by the accepted porosity (see **Table 1.2**). All layer depths shall be uniform with regard to surface area. The filter bed surface should generally be flat so the bioretention area fills up like a bathtub. See **Section 5.5** for material specifications.

Table 1.2 Bioretention Typical Section for Water Quality Calculations					
Infiltration (i)	**i > 0.5"/hr (no underdrain permitted)**		**0.1"/hr< i ≤0.5"hr (underdrain required)**		**Porosity Value (n)**
Layer	**Level 1 (inches)**	**Level 2 (inches)**	**Level 1 (inches)**	**Level 2 (inches)**	
Ponding	8				1.0
Surface Cover*	3	3	3	3	N/A
Media	24-72	36-72	24-72	36-72	0.25
Choker	3	3	3	3	0.40
Reservoir	0-9	9	9	9	0.40
Sump*	0	0	0	12	N/A

* Cannot be used in De and surface area calculations.

The equivalent storage depth for Level 1 is therefore computed as:

Equation 1.1. Bioretention Level 1 Design Storage Depth

$$\text{Equivalent Storage Depth} = D_E = n_1(D_1) + n_2(D_2) + \cdots$$

$$D_E = (2 \text{ to } 6 \text{ ft.} \times 0.25) + (1 \text{ ft} \times 0.40) + (0.67 \text{ ft} \times 1.0) = 1.57 \text{ to } 2.57 \text{ ft.}$$

Where n_1 and D_1 are for the first layer, etc.

And the equivalent storage depth for Level 2 is computed as:

Equation 1.2. Bioretention Level 2 Design Storage Depth

$$D_E = (3 \text{ to } 6 \text{ ft.} \times 0.25) + (1 \text{ ft.} \times 0.40) + (0.67 \text{ ft} \times 1.0) = 1.82 \text{ to } 2.57 \text{ ft}$$

While this method is simplistic, simulation modeling has proven that it yields a total storage volume equivalent to 80% total average rainfall volume removal for infiltration rates from 0.5 in/hr through 1.2 in/hr.

Therefore, the Level 1 Bioretention Surface Area (SA) is computed as:

Equation 1.3. Bioretention Level 1 Design Surface Area

$$SA \text{ (sq. ft.)} = [(1.10 * T_v) - \text{the volume reduced by an upstream SCM}] / D_E$$

And the Level 2 Bioretention Surface Area is computed as:

Equation 1.4. Bioretention Level 2 Design Surface Area

$$SA \text{ (sq. ft.)} = [(1.25 * Tv) - \text{the volume reduced by an upstream SCM}] / D_E$$

Where:

SA = Minimum surface area of bioretention filter (sq. ft.)

D_E = *Equivalent Storage Depth (ft.)*

T_v = Treatment Volume (cu. ft.) = [(1.0 in.)(R_v)(A)*3630]

5.2.2 Stormwater Quantity

It is recommended that rain events larger than the 1-inch storm bypass bioretention areas to prevent additional maintenance burden. However, if designed with sufficient volume and appropriate outlet structures, peak attenuation control may be provided by the bioretention area. Hydrologic calculations utilizing the SCS method may be necessary to demonstrate pre versus post peak flow rates.

Surface Storage. Designers may be able to create additional surface storage for flow attenuation by expanding the surface ponding without necessarily increasing the bioretention footprint. In other words, the engineered soil media would only underlay part of the surface area of the bioretention (see **Figure 1.3**). During the 100-year storm event, a maximum ponding depth of 15 inches above the top of the surface cover is allowed. Water quality calculations are limited to 8 inches of ponding

Subsurface Storage. Designers may be able to create additional subsurface storage for flow attenuation by increasing the subsurface volume without necessarily increasing the bioretention footprint. Additional volume can be provided by increasing the depth of media, stone, or approved proprietary storage products. Subsurface storage will not be allowed without sufficient infiltration (see **Section 5.1**). The bioretention depth including subsurface storage shall not exceed 10 feet.

Adjusted CN. With infiltration rates greater than 0.5 inch per hour (see **Section 5.1**), the removal of volume by bioretention changes the runoff depth entering downstream flood control facilities. An approximate approach to accounting for the removal of volume is to calculate an "effective SCS curve number" (CN_{adj}), which is less than the actual curve number (CN). CN_{adj} can then be used in hydrologic calculations and in routing. This method is detailed in Volume 5 Section 3.2.5.

5.3 Pretreatment

Pretreatment facilities must always be used in conjunction with bioretention to remove floatables and sediment to prevent clogging and failure. Every infiltration practice must include multiple pretreatment techniques, although the nature of pretreatment practices depends on the type of flow received. Pretreatment measures should be designed to evenly spread runoff across the entire width of the bioretention area. Several pretreatment measures are feasible, depending on the scale of the bioretention practice and whether it receives sheet flow, shallow concentrated flow or deeper concentrated flows. The number, volume and type of acceptable pretreatment techniques needed for the types of receiving flow are found in **Table 1.3**.

Volumetric pretreatment practices, such as forebays, are sized based on a percentage of the required treatment volume of the GIP. The percentage requirement for the pretreatment practice is exclusive of the required treatment volume for the GIP. Exclusive, in this application, is defined as being separate from the required treatment volume of the GIP. The volume provided by pretreatment practices cannot be included in the calculation for overall treatment volume provided by the GIP.

Table 1.3. Required Pretreatment Elements for Infiltration Practices

Flow Type	***Pretreatment Options***
Point/ Concentrated*	• ***Forebay*** ○ *15% pretreatment volume (exclusive)* ○ *enhanced check dam (TDOT EC-STR-6A); or approved equivalent* ○ *flat bottom without stone* • ***Proprietary structure (MWS approval)***
Sheet	*Gravel diaphragm to grass filter strip (15' with maximum 3:1 slope)*
Upstream GIP	*Outlet protection may be required at upstream GIP outfall*

* Roof drains may bypass the forebay and directly enter the bioretention area with sufficient flow dissipation; however, the forebay volume shall be calculated using the total treatment volume of the GIP.

5.4 Conveyance and Overflow

For On-line bioretention: An overflow structure should always be incorporated into on-line designs to safely convey larger storms through the bioretention area. Common overflow systems within bioretention practices consist of an outlet structure(s) and/or emergency spillway in compliance with the Stormwater Management Manual, Volume 2, Section 8.

Off-line bioretention: Off-line designs are preferred (see **Figure 1.8** for an example). One common approach is to create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the facility. In this case, the higher flows do not pass over the filter bed and through the facility, and additional flow is able to enter as the ponding water filtrates through the soil media.

Another option is to utilize a low-flow diversion or flow splitter at the inlet to allow only the Treatment Volume to enter the facility. This may be achieved with a weir or curb opening sized for the target flow, in combination with a bypass channel. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency.

5.5 Bioretention Material Specifications

Table 1.4 outlines the standard material specifications used to construct bioretention areas.

Table 1.4. Bioretention Material Specifications

Material	Specification	Notes
Surface Layer	• Shredded hardwood • Hardwood bark • River stone • Coir or jute matting • Turf	Lay a 3-inch layer on the surface of the filter bed in order to suppress weed growth & prevent erosion. Stone shall not comprise more than 50% of the surface area.
Filter Media Composition (by volume)	• 70% - 85% sand; • 10%-30% silt + clay, with clay $\leq$ 10%; and • 5% to 10% organic matter	The volume of filter media based on 110% of the plan volume, to account for settling or compaction. Contact staff for testing procedures.
Geotextile	Use a non-woven geotextile fabric with a flow rate of > 110 gal./min./ft^2 (e.g., Geotex 351 or equivalent)	Apply only to the sides and above the underdrain (2'-4' wide strip). AASHTO M288-06, ASTM D4491 & D4751
Choker Layer	#8 or #89 clean washed stone	Meet TDOT Construction Specifications.
Reservoir Layer	#57 clean washed stone	Meet TDOT Construction Specifications.
Underdrain	6-inch dual wall HDPE or SDR 35 PVC pipe with 3/8-inch perforations at 6 inches on center	AASHTO M 252 Place perforated pipe at base of reservoir layer.
Cleanout	6-inch SDR 35 PVC pipe with vented cap	Provide cleanouts at the upper end of the underdrain.
Observation Well	6-inch SDR 35 PVC pipe with vented cap and anchor plate	Number of wells equals the number of test pits required for infiltration testing (see Appendix 1-A)
Sump Layer	#57 clean washed stone	Meet TDOT Construction Specifications.

5.6 Bioretention Planting Plans

A landscaping plan must be provided for each bioretention area. Minimum plan elements shall include the proposed planting plan for the surface area of the bioretention, the list of planting stock, sources of plant species, sizes of plants, and the planting sequence along with post-nursery care and initial maintenance requirements. The planting plan must address 100% of the planting area and achieve a surface area coverage of at least 75% in the first two years. Native plant species are preferred over non-native species, but some ornamental species may be used for landscaping effect if they are not aggressive or invasive. **Appendix 1-D** lists native plant species suitable for use in bioretention. For a bioretention area to qualify for Level 2 Design, a minimum of one tree must be planted for every 400 square feet.

The planting plan must be prepared by a qualified Landscape Architect. The Landscape Architect shall certify the planting plan with certification statement, located on the bioretention planting plan. Standard certification statement can be found in **Appendix 1-B**.

Recommended planting templates include the following:

- Ornamental planting. This option includes perennials, sedges, grasses, shrubs, and/or trees in a mass bed planting. This template is recommended for commercial sites where visibility is important. This template requires maintenance similar to traditional landscape beds.
- Meadow. This is a lower maintenance approach that upon maturity may resemble a wildflower meadow or prairie. It can include a mixture of densely planted grasses and/or perennials.

Designs should utilize more mature plants densely spaced to achieve coverage and minimize maintenance. Planting species in groups will help maintenance staff differentiate weeds from desired species. Establishing a solid ground cover can also prevent weed intrusion and eliminate the need for continued mulching. **Table 1.5** contains the recommended number of perennials, grasses, and shrubs per one hundred square feet of bioretention area based upon the spacing provided in **Appendix 1-D**.

Example: A 300 square foot meadow bioretention is designed with one-gallon perennials and grasses planted on 24" centers. How many plants should be included in the design?

300 sq. ft (29 plants/100 sq. ft) = 87 plants

Table 1.5 Plant Spacing for Perennials, Grasses, Sedges and Shrubs

Spacing (O.C.)	Plants per 100 sq.ft.
18" o.c.	51.2
24" o.c.	29
28" o.c.	22
30" o.c.	18.5
36" o.c.	12.8
42" o.c.	10
4' o.c.	7.23
5' o.c.	4.61
6' o.c.	3.2
8' o.c.	1.8

SECTION 6: SPECIAL CASE DESIGN ADAPTATIONS

6.1 Shallow Bedrock and Groundwater Connectivity

Many parts of Nashville have shallow bedrock, which can constrain the application of deeper bioretention areas (particularly Level 2 designs). In such settings, other GIPs may be more applicable. For more information on bedrock depths download the GIS data set from: http://water.usgs.gov/GIS/metadata/usgswrd/XML/regolith.xml.

6.2 Karst

Karst regions are found in much of Middle Tennessee, which complicates both land development and stormwater design. Infiltrative practices shall not be used in any area with a high risk of sinkhole formation.

6.3 Hotspots

Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk for spills, leaks or illicit discharges. Bioretention designs shall not be used in any area with a hotspot designation without appropriate pretreatment, impermeable barriers, and MWS staff approval. Staff may also require additional treatment for runoff from hotspots.

6.4 Internal Water Storage

Enhanced water quality can be achieved by utilizing an Internal Water Storage (IWS) system in bioretention areas. Utilizing an IWS configuration can create an anaerobic zone that can increase annual runoff reduction rates, promote denitrification, reduce levels of other pollutants, and increase groundwater recharge in bioretention areas (See **Figures 1.4 and 1.5)**. An IWS system shall be used for water quality only <u>and in an offline configuration</u>. A minimum field-verified infiltration rate of 0.1 inches per hour is required in order to count the stone reservoir as storage volume. The following sections detail two different methods for creating an IWS system.

Cobra Head Style. The perforated underdrain is placed at the bottom of the stone reservoir layer and extends the full length of the bioretention. An upturned 90-degree elbow is added to the end of the underdrain. The underdrain transitions to a solid wall pipe until it is 12 inches from the top of the bioretention media. Another elbow is added and the outlet pipe discharges into a downstream structure or conveyance. The IWS will allow for a larger volume of water to percolate into the native soils while providing a high flow bypass when the exfiltration rate is exceeded. This IWS can reduce the cost of construction since the invert of the outlet is not as deep as a traditional underdrain configuration.

Weir. For this IWS configuration the underdrain transitions to a solid wall pipe prior to exiting the stone reservoir layer and is directed towards an outlet structure. This run of pipe should be straight and be set at a minimal grade. The outlet structure should be designed to facilitate maintenance. In order to create the higher outlet elevation, the outlet structure is configured with an internal weir wall with the top of the weir set a maximum of 12 inches from the top of the bioretention media. This design variant can also include a drain orifice in the bottom of the weir to allow the sump to be drained if, over time, the exfiltration into the soil becomes restricted. This orifice should be covered with a plate that is clearly marked to indicate that it remain blocked under normal operating conditions.

SECTION 7: CONSTRUCTION

7.1 Construction

Construction Stage Erosion and Sediment Controls. Small-scale bioretention areas should be fully protected by silt fence and construction fencing to prevent sedimentation and compaction. Ideally, bioretention should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. Sediment traps or basins may be located within bioretention excavation limits during construction. However, these must be accompanied by notes and graphic details on the erosion prevention and sediment control (EPSC) plan specifying that the maximum excavation depth at the construction stage must be at least 1 foot above the post-construction subgrade elevation. The plan must also show the proper procedures for converting the temporary sediment control practice to a bioretention facility, including dewatering, cleanout and stabilization.

Excavation. The proposed site should be checked for existing utilities prior to any excavation. It is very important to minimize compaction of both the base of the bioretention area and the required backfill. When possible, excavators should work from the sides of the bioretention area to remove original soil. If the bioretention area is excavated using a loader, the contractor must use wide track or marsh track equipment, or light equipment with turf type tires. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high-pressure tires will cause excessive compaction resulting in reduced infiltration rates and is not acceptable. Compaction will significantly contribute to design failure.

7.2 Bioretention Installation

Construction should take place during appropriate weather conditions. The following is a typical construction sequence to properly install a bioretention basin. These steps may be modified to reflect different bioretention applications or expected site conditions:

Step 1. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area 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 2. Ensure that the entire contributing drainage area has been stabilized prior to bioretention construction. Otherwise, use EPSC measures as outlined in **Section 7.1**.

Step 3. Excavation of the bioretention area should follow the guidelines found in **Section 7.1**. 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 4. It may be necessary to rip the bottom soils to a depth of 6 to 12 inches to promote greater infiltration.

Step 5. Install all layers, components, and landscaping of the bioretention per plans. Media shall be tested per MWS standards. Irrigate plantings as needed.

Step 6. Conduct the final construction inspection (see **Section 8**). Then log the GPS coordinates for each bioretention facility and submit them to MWS.

SECTION 8: AS-BUILT REQUIREMENTS

After the bioretention area has been constructed, the owner/developer must have an as-built certification of the bioretention area conducted by a registered Professional Engineer. The as-built certification verifies that the GIP was installed per the approved plan. The following items shall be provided in addition to the as-built requirements found in SWMM Volume 1.

1. Landscape Architect letter certifying that the SCM plantings have been installed in general conformance with the approved grading plans and, with proper maintenance, should achieve 75% coverage within the first two years.
2. The Engineer shall include a copy of the GIP summary table found in Appendix 1-E.
3. Supporting documents such as invoices, photos, and media test results shall be included in the submittal package.

SECTION 9: MAINTENANCE

9.1 Maintenance Document

The requirements for the Maintenance Document are in Appendix C of Volume 1 of the Manual. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long-Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities.

9.2 First Year Maintenance Operations

Successful establishment of bioretention areas requires that the following tasks be undertaken in the first year following installation:

- ***Initial inspections.*** For the first 6 months following construction, the site should be inspected at least twice after storm events that exceed 0.5 inch of rainfall.
- ***Spot Reseeding.*** Inspectors should look for bare or eroding areas in the contributing drainage area or around the bioretention area, and make sure they are immediately stabilized with grass cover.
- ***Fertilization.*** One-time, spot fertilization may be needed for initial plantings.
- ***Watering.*** Depending on rainfall, watering may be necessary 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.*** Since up to 10% of the plant stock may die off in the first year, 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. The typical thresholds below which replacement is required are 85% survival of plant material and 100% survival of trees.

9.3 Maintenance Inspections

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each bioretention area. The following is a list of some of the key maintenance problems to look for:

- Check to see if 75% to 90% cover (mulch plus vegetative cover) has been achieved in the bed, and measure the depth of the remaining mulch.
- Check for sediment buildup at curb cuts, gravel diaphragms or pavement edges that prevents flow from getting into the bed, and check for other signs of bypassing.
- Check for any winter- or salt-killed vegetation, and replace it with hardier species.
- Note presence of accumulated sand, sediment and trash in the pretreatment cell or filter beds, and remove it.
- Inspect bioretention side slopes and grass filter strips for evidence of any rill or gully erosion, and repair it.
- Check the bioretention bed for evidence of mulch flotation, excessive ponding, dead plants or concentrated flows, and take appropriate remedial action.
- Check inflow points for clogging, and remove any sediment.
- Look for any bare soil or sediment sources in the contributing drainage area, and stabilize them immediately.
- Check for clogged or slow-draining soil media, a crust formed on the top layer, inappropriate soil media, or other causes of insufficient filtering time, and restore proper filtration characteristics.

9.4 Routine and Non-Routine Maintenance Tasks

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. Pesticides should be limited to environmentally friendly pesticides that don’t pose the risk of bioaccumulation within the underlying soils and water tables. Pesticide use should follow label instructions and stormwater basins should be considered aquatic sites. Some acceptable uses of pesticides would be around the edge of bioretention basins to prevent invasive species from propagating within the basin.

A customized maintenance schedule must be prepared for each bioretention facility, since the maintenance tasks will differ depending on the scale of bioretention, the landscaping template chosen, and the type of surface cover. A generalized summary of common maintenance tasks and their frequency is provided in **Table 1.6**.

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 (try the easiest things first, as listed below):

- 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 standpipe indicate standing water, then the underdrain must be clogged and will need to be snaked.
- Remove accumulated sediment and till 2 to 3 inches of sand into the upper 8 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 gravel storage zone 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

Table 1.6. Suggested Annual Maintenance Activities for Bioretention

Maintenance Tasks	Frequency
Mowing of grass filter strips and bioretention turf cover	At least 4 times a year
Spot weeding, erosion repair, trash removal, and mulch raking	Twice during growing season
Add reinforcement planting to maintain desired vegetation density	As needed
Remove invasive plants using recommended control methods	As needed
Stabilize the contributing drainage area to prevent erosion	As needed
Spring inspection and cleanup	Annually
Supplement mulch to maintain a 3-inch layer	Annually
Prune trees and shrubs	Annually
Remove sediment in pretreatment cells and inflow points	Once every 2 to 3 years
Replace the mulch layer	Every 3 years

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

The following is a list of some community and environmental concerns that may arise when infiltration practices are proposed:

Nuisance Conditions. Poorly designed infiltration practices can create potential nuisance problems such as basement flooding, poor yard drainage and standing water. In most cases, these problems can be minimized through proper adherence to the setback, soil testing and pretreatment requirements outlined in this specification.

Mosquito Risk. Infiltration practices have some potential to create conditions favorable to mosquito breeding, if they clog and have standing water for extended periods. Proper installation and maintenance of the bioretention area will prevent these conditions from occurring.

Groundwater Injection Permits. Groundwater injection permits are required if the infiltration practice is deeper than the longest surface area dimension of the practice. Designers should investigate whether or not a proposed infiltration practice is subject to Tennessee groundwater injection well permit requirements.

SECTION 11: REFERENCES

Brown, R.A., Hunt, W.F. and S.G. Kennedy. 2009. "Designing Bioretention with an Internal Water Storage Layer." *North Carolina Cooperative Extension Service Bulletin*. Urban Waterways Series. AG-588-19W. North Carolina State University. Raleigh, NC.

Chesapeake Stormwater Network (CSN). 2008. *Technical Bulletin 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed.* Version 1.0. Baltimore, MD. Available online at: http://www.chesapeakestormwater.net/all-things-stormwater/stormwater-guidance-for-karst-terrain-in-the-chesapeake-bay.html

CWP. 2007. *National Pollutant Removal Performance Database, Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Hirschman, D., L. Woodworth and S. Drescher. 2009. *Technical Report: Stormwater BMPs in Virginia's James River Basin – An Assessment of Field Conditions and Programs*. Center for Watershed Protection. Ellicott City, MD.

Hunt, W.F. III and W.G. Lord. 2006. "Bioretention Performance, Design, Construction, and Maintenance." *North Carolina Cooperative Extension Service Bulletin*. Urban Waterways Series. AG-588-5. North Carolina State University. Raleigh, NC.

Hyland, S. 2005. "Analysis of sinkhole susceptibility and karst distribution in the Northern Shenandoah Valley (Virginia): impacts for LID site suitability models." M.S. Thesis. Virginia Polytechnic Institute and State University. Blacksburg, VA.

Lake County, OH. *Bioretention Guidance Manual*. Available online at:
http://www2.lakecountyohio.org/smd/Forms.htm

LIDC. 2003. *Bioretention Specification*. The Low Impact Development Center, Inc, Beltsville, MD. Available at:
http://www.lowimpactdevelopment.org/epa03/biospec.htm.

Maryland Department of the Environment. 2001. *Maryland Stormwater Design Manual*.
htp:/www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater design/index.asp

Minnesota Stormwater Steering Committee (MSSC). 2005. *The Minnesota Stormwater Manual*.

MWS, 2011. *Rain Gardens for Nashville*. Metro Water Services Stormwater NPDES Department, Nashville, TN.

North Shore City. 2007. *Bioretention Design Guidelines*. Sinclair, Knight and Merz. Auckland, New Zealand.

Prince George's Co., MD. *Bioretention Manual*. Available online at:
http://www.goprincegeorgescounty.com/Government/AgencyIndex/DER/ESD/Bioretention/bioretention.asp?nivel =fold men u(7)

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Schueler et al. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

State of Virginia BMP Specification No. 8 – Bioretention (2010).

Virginia Department of Conservation and Recreation (VADCR), 2010. *Stormwater Design Specification No. 9: Bioretention*, version 1.7. Virginia Department of Conservation and Recreation, Richmond, VA.

Virginia Department of Conservation and Recreation (VADCR), 2013. *Stormwater Design Specification No. 9: Bioretention*, version 2.0. Virginia Department of Conservation and Recreation, Richmond, VA.

Wisconsin Department of Natural Resources. *Stormwater Management Technical Standards*. http://www.dnr.state.wi.us/org/water/wm/nps/stormwater/techstds.htm#Post

APPENDIX 1-A

INFILTRATION SOIL TESTING PROCEDURES

I. Test Pit/Boring Procedures

1. The number of required test pits or standard soil borings is based on proposed infiltration area:
   - < 1,000 ft² = 2 tests
   - 1,000 – 10,000 ft² = 4 tests
   - >10,000 ft² = 4 tests + 1 test for every additional 5,000 ft²
2. The location of each test pit or standard soil boring should correspond to the location of the proposed infiltration area and be performed in in situ soils.
3. Excavate each test pit or penetrate each standard soil boring to a depth at least 2 feet below the bottom of the proposed infiltration area.
4. If the groundwater table is located within 2 feet of the bottom of the proposed facility, determine the depth to the groundwater table immediately upon excavation and again 24 hours after excavation is completed.
5. Determine the USDA or Unified Soil Classification system textures at the bottom of the proposed infiltration area and at a depth that is 2 feet below the bottom. All soil horizons should be classified and described.
6. If bedrock is located within 2 feet of the bottom of the proposed infiltration area, determine the depth to the bedrock layer.
7. Test pit/soil boring stakes should be left in the field to identify where soil investigations were performed.

II. Infiltration Testing Procedures

1. The number of required infiltration tests is based on proposed infiltration area:
   - < 1,000 ft² = 2 tests
   - 1,000 – 10,000 ft² = 4 tests
   - >10,000 ft² = 4 tests + 1 test for every additional 5,000 ft²
2. The location of each infiltration test should correspond to the location of the proposed infiltration area.
3. Install a test casing (e.g., a rigid, 4 to 6-inch diameter pipe) to the bottom of the proposed infiltration area. Record the testing elevation.
4. Remove all loose material from the sides of the test casing and any smeared soil material from the bottom of the test casing to provide a natural soil interface into which water may percolate. If desired, a 2-inch layer of coarse sand or fine gravel may be placed at the bottom of the test casing to prevent clogging and scouring of the underlying soils. Fill the test casing with clean water to a depth of 2 feet and allow the underlying soils to presoak for 24 hours.
5. After 24 hours, refill the test casing with another 2 feet of clean water and measure the drop in water level within the test casing after one hour. Repeat the procedure three (3) additional times by filling the test casing with clean water and measuring the drop in water level after one hour. A total of four (4) observations must be completed.
6. The infiltration rate of the underlying soils may be reported either as the average of all four observations or the value of the last observation. The infiltration rate shall be reported in terms of inches per hour along with the elevations and locations of the test pits. Locations shall be shown on site map.
7. Infiltration testing may be performed within an open test pit or a standard soil boring. After infiltration testing is completed, the test casing should be removed, and the test pit or soil boring should be backfilled and restored.

APPENDIX 1-B
STANDARD NOTES

Required Bioretention Notes:

- Contractor, Engineer, or Owners Representative shall notify MWS NPDES Staff at least 48 hours prior to the installation of the bioretention filter media. At the completion of installation, the above referenced person will collect one sample per bioretention area for analysis and confirmation of the filter media as defined by GIP-01. Media testing not required when using a certified media product.
- I hereby certify that this bioretention planting plan is in keeping with the requirements listed in GIP-01 Section 5.6. Only native species and/or non-invasive species of plants were used in the design of this bioretention planting plan. This plan will achieve at least 75% surface area coverage within the first two years, and has the minimum amount of required trees.
- Vehicular and equipment traffic shall be prohibited in the bioretention area to prevent compaction and sediment deposition.

APPENDIX 1-C
STANDARD DETAILS

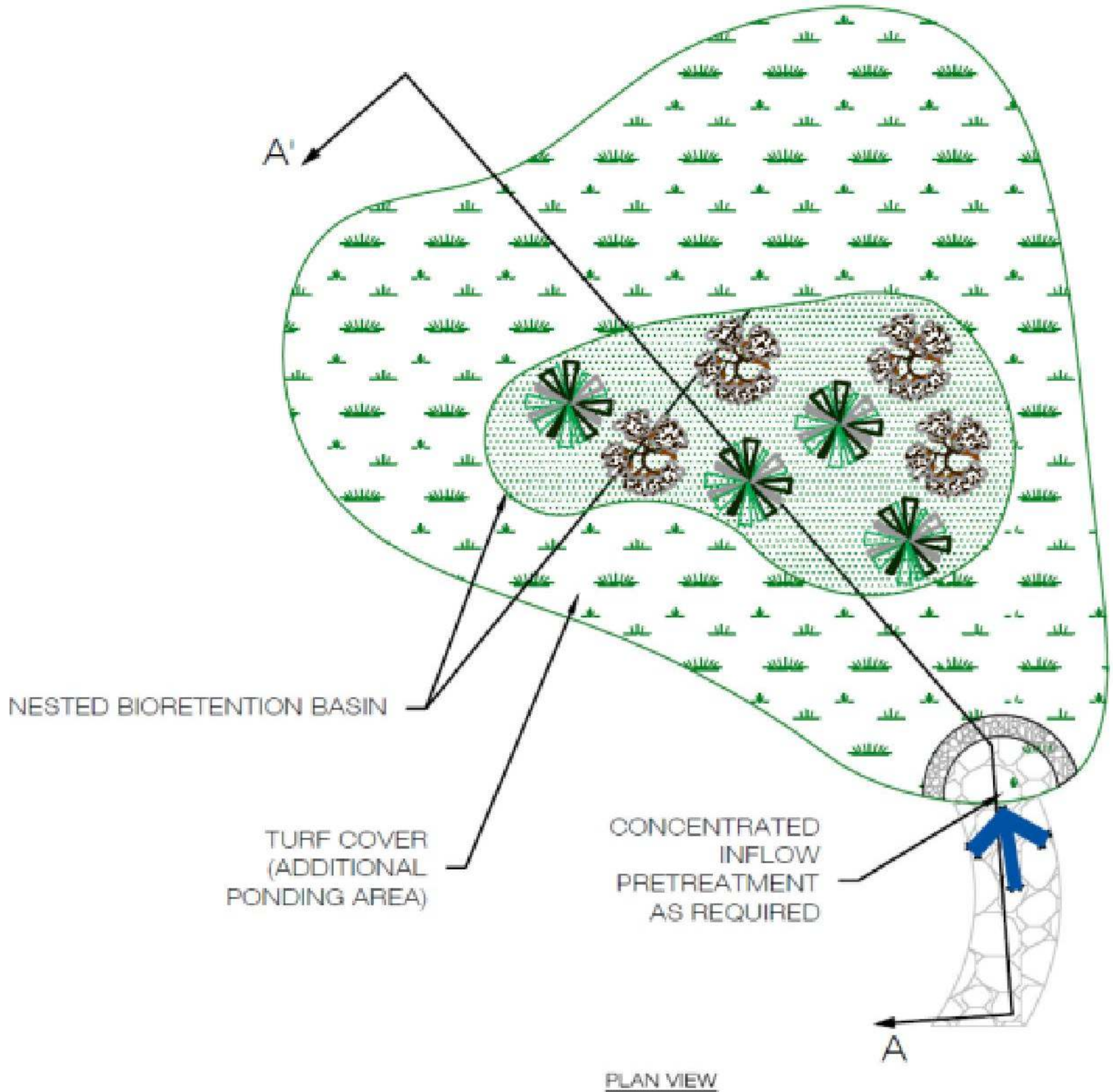
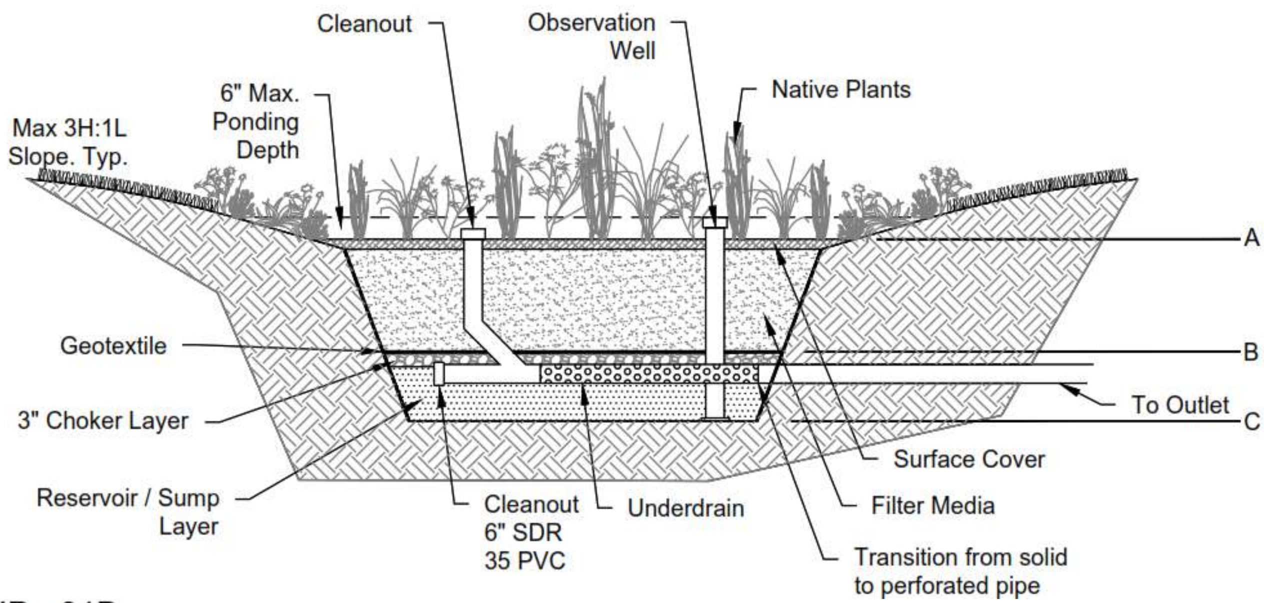
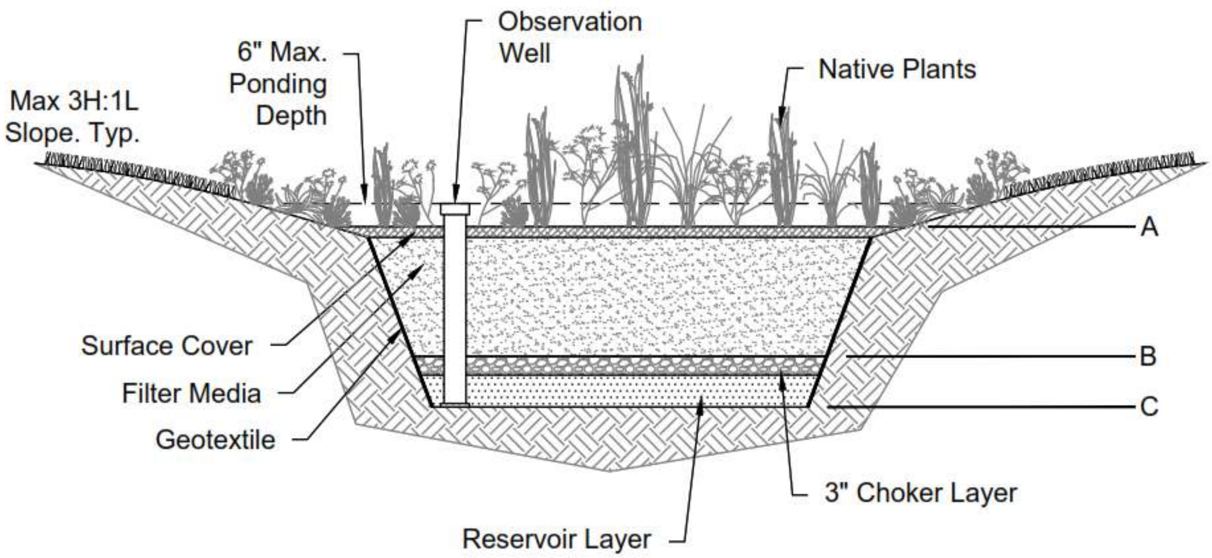


Figure 1.2a. Typical Detail of Bioretention with Additional Surface Ponding (source: VADCR, 2010, MWS edited 2020)

GIP - 01A
BIORETENTION WITH
UNDERDRAIN



GIP - 01B
BIORETENTION
WITHOUT
UNDERDRAIN



(source: VADCR, 2010, MWS edited 2020)

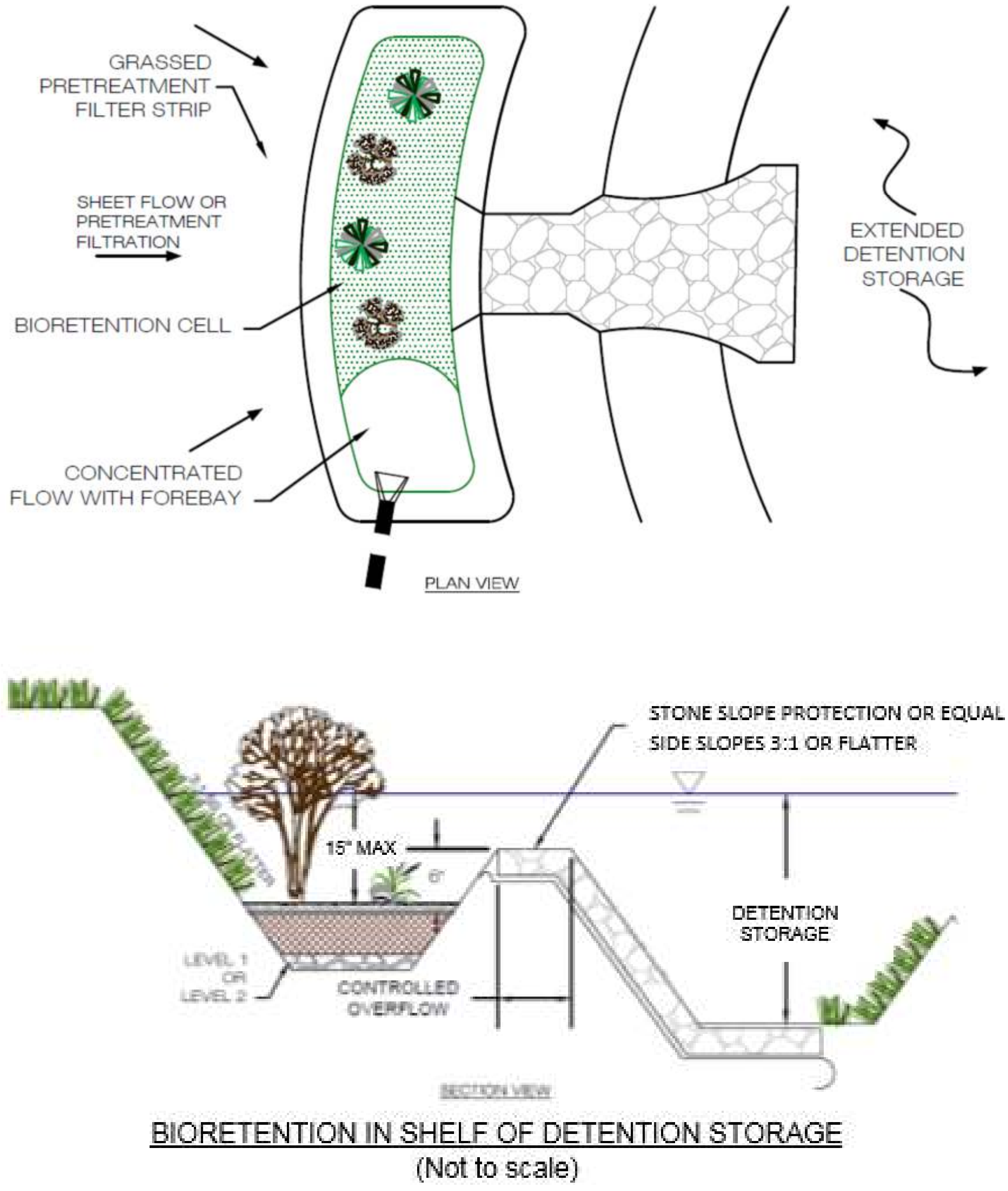


Figure 1.3. Typical Detail of a Bioretention Basin within the Upper Shelf of an ED Pond (source: VADCR, 2010, MWS edited 2020)

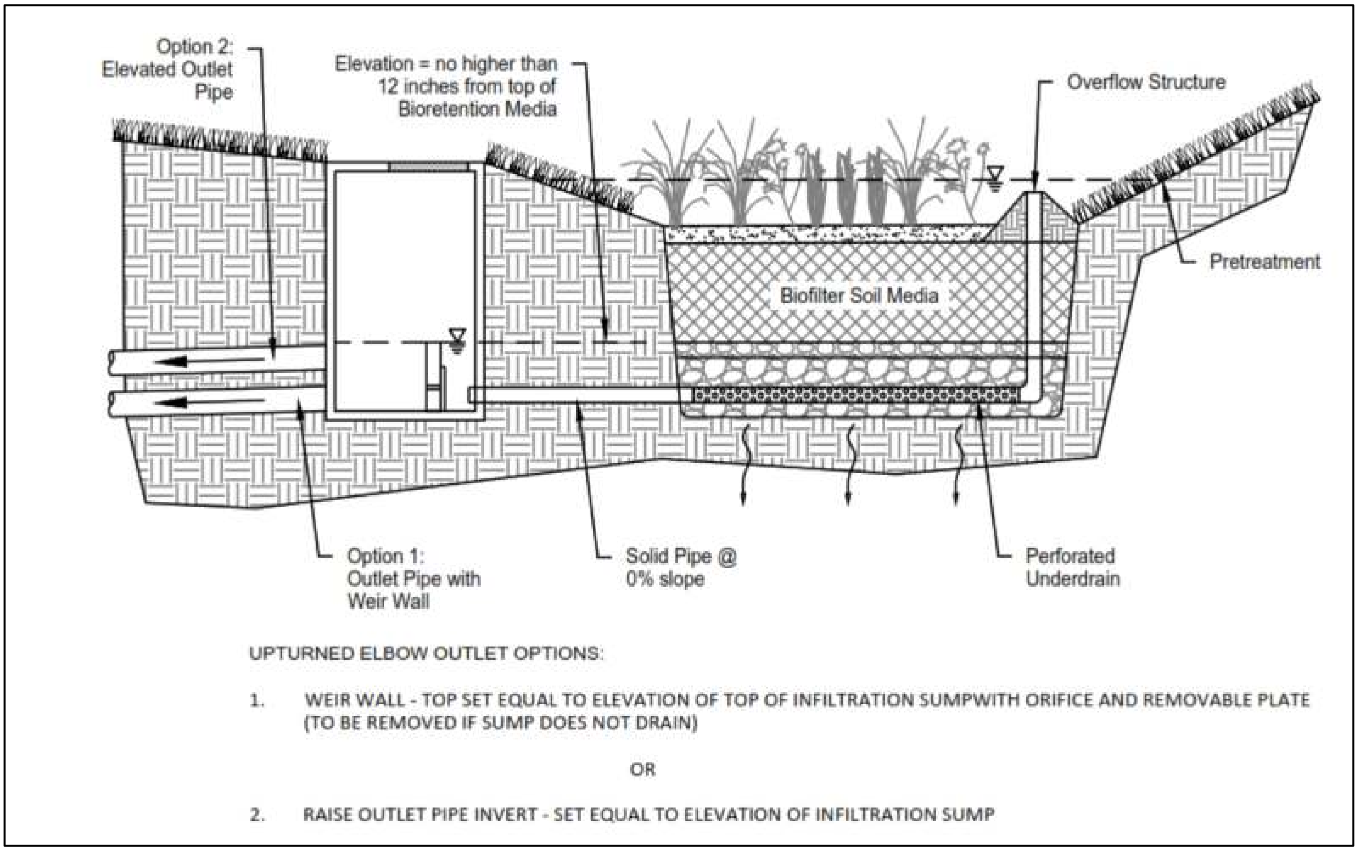


Figure 1.4. Typical Bioretention Basin Level 2: Infiltration Sump with Internal Water Storage (source: VADCR, 2013, MWS edited 2020)

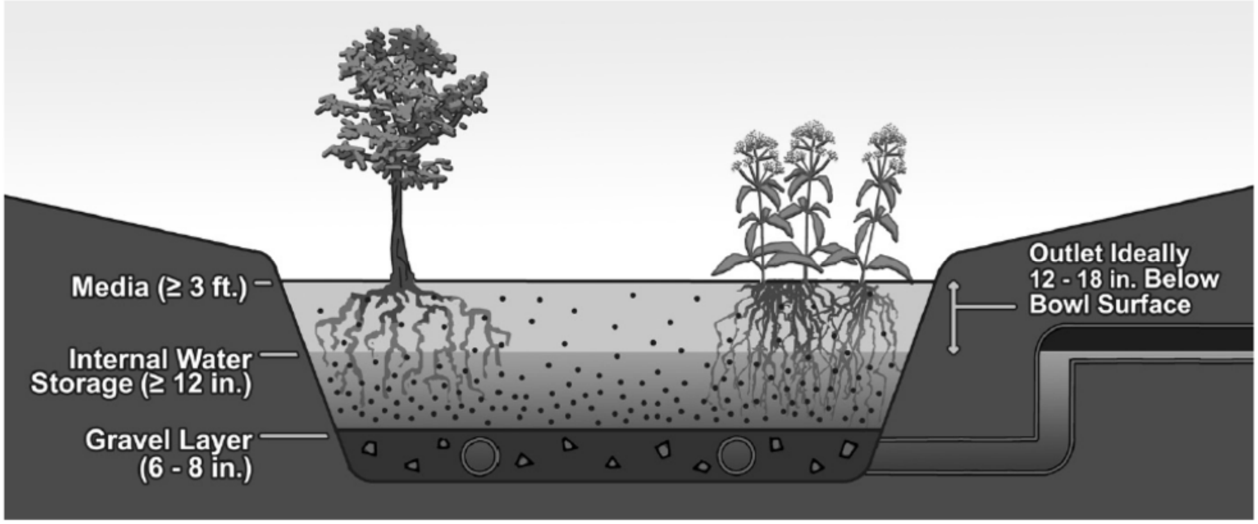


Figure 1.5. Bioretention with Internal Water Storage (source: Brown, 2009)

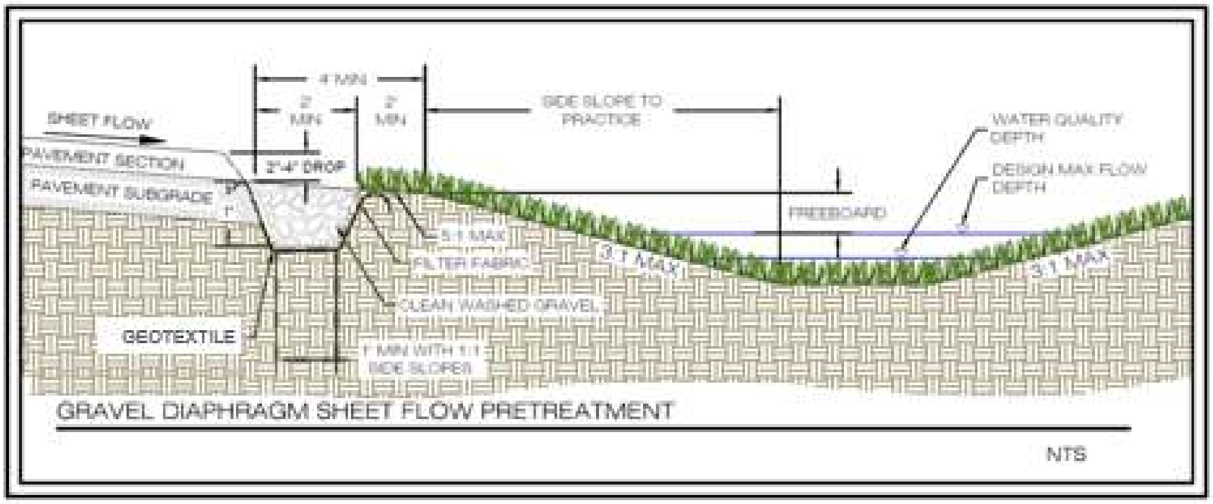


Figure 1.6- Pretreatment Option – Gravel Diaphragm for Sheet (source: VADCR, 2010, MWS edited 2020)

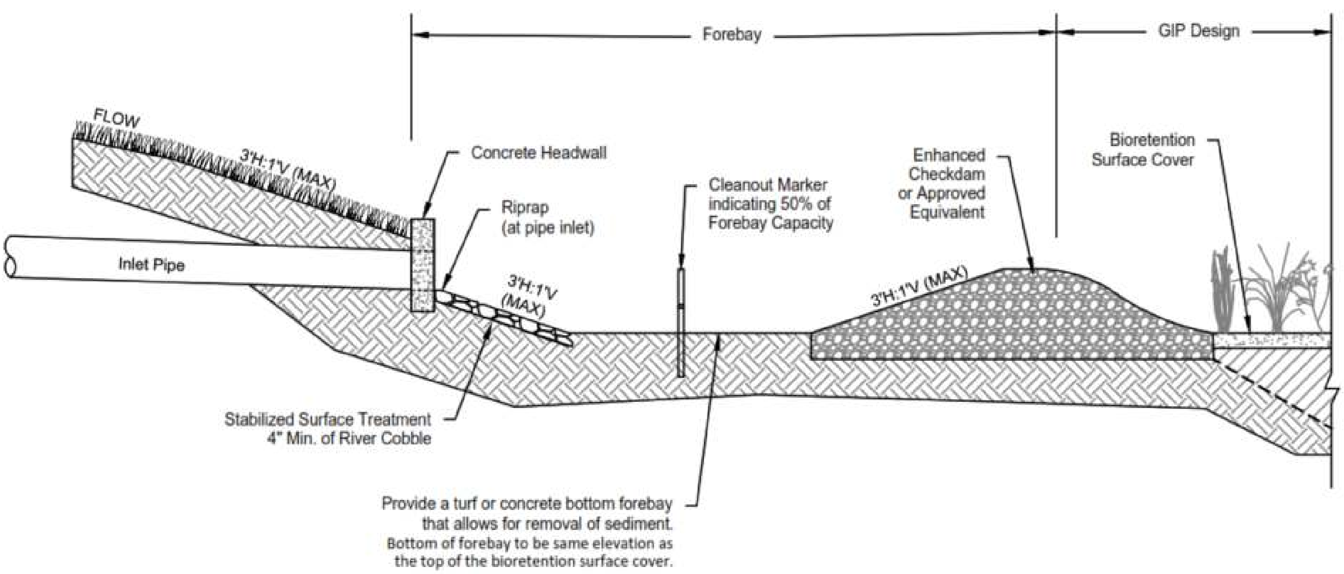


Figure 1.7: Forebay Detail

PLAN VIEW

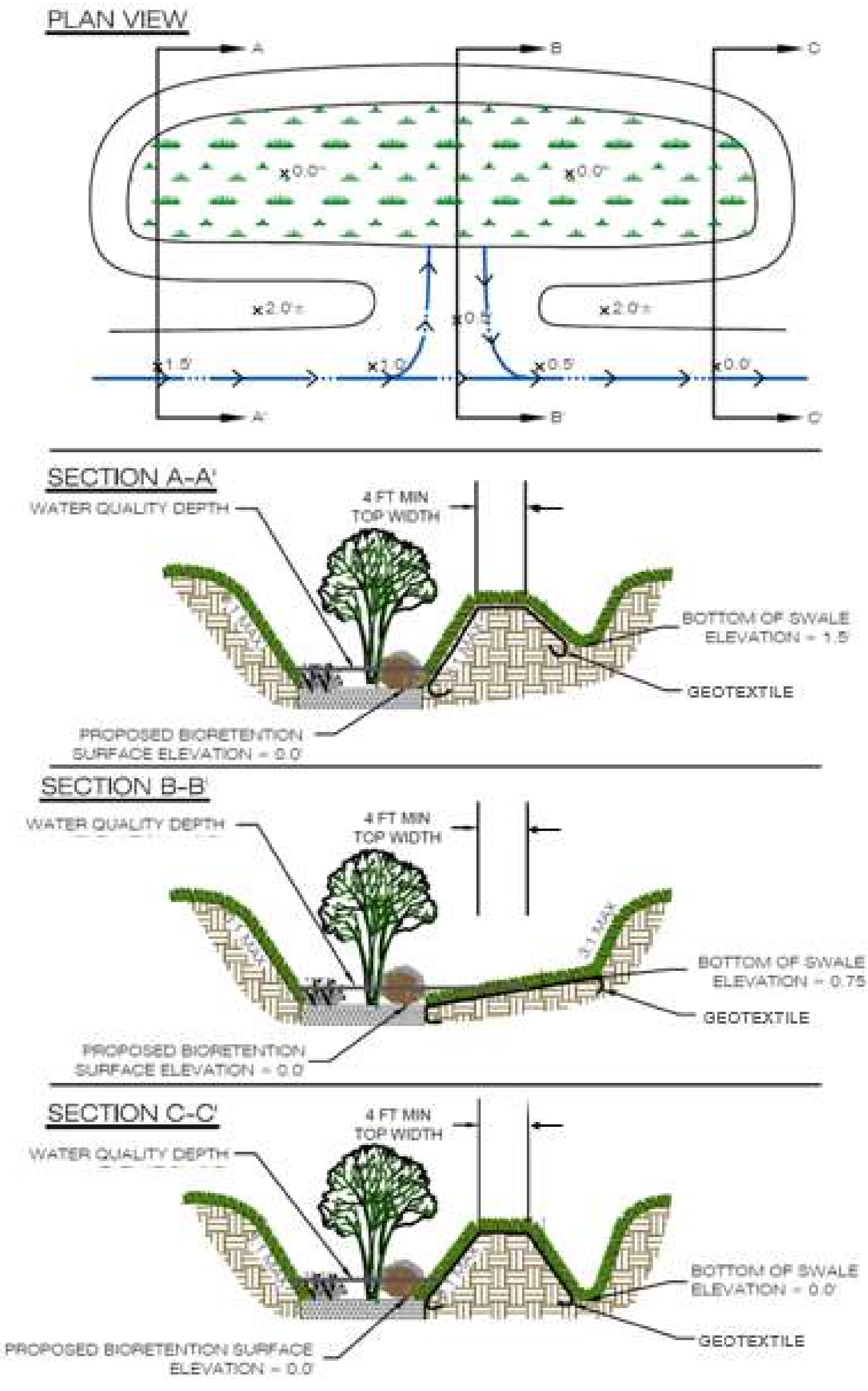


Figure 1.8. Typical Details for Off-Line Bioretention
(source: VADCR, 2010, MWS edited 2020)

APPENDIX 1-D

NATIVE PLANTINGS

Popular Native Perennials for Bioretention – Full Sun						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Asclepias incarnate	Marsh milkweed	Plugs – 1 gal.	1 plant/24" o.c.	Wet	Pink	3-4'
Asclepias purpurescens	Purple milkweed	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Purple	3'
Asclepias syriaca	Common milkweed	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Orange	2-5'
Asclepias tuberosa	Butterfly milkweed	Plugs – 1 gal.	1 plant/18" o.c.	Dry-moist	Orange	2'
Asclepias verdis	Green milkweed	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Green	2'
Asclepias verdicillata	Whorled milkweed	Plugs – 1 gal.	1 plant/18" o.c.	Moist	White	2.5'
Aster laevis	Smooth aster	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Blue	2-4'
Aster novae-angliae	New England aster	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Blue	2-5'
Aster sericeus	Silky aster	Plugs – 1 gal.	1 plant/18" o.c.	Dry	Purple	1-2'
Chamaecrista fasciculata	Partridge pea	Plugs – 1 gal.	1 plant/18" o.c.	Dry	Yellow	1-2'
Conoclinium coelestinum	Mist flower	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Blue	1-2'
Coreopsis lanceolata	Lance-leaf coreopsis	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Yellow	6-8'
Echinacea pallida	Pale purple coneflower	Plugs – 1 gal.	1 plant/18" o.c.	Dry	Purple	2-3'
Echinacea purpurea	Purple coneflower	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	3-4'
Eupatorium perfoliatum	Boneset	Plugs – 1 gal.	1 plant/24" o.c.	Wet	White	3-5'
Eupatorium purpureum	Sweet Joe-Pye Weed	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Purple	3-6'
Iris virginica	Flag Iris	Plugs – 1 gal.	1 plant/18" o.c.	Moist-Wet	Blue	2'
Liatris aspera	Rough blazingstar	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	2-5'
Liatris microcephalla	Small-headed	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	3'
Liatris spicata	Dense blazingstar	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Purple	1.5'
Liatris squarrulosa	Southern blazingstar	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	2-6'
Lobelia cardinalis	Cardinal flower	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Red	2-4'
Monarda didyma	Bee balm	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Red	3'
Monarda fistulosa	Wild bergamot	Plugs – 1 gal	1 plant/18" o.c.	Moist	Purple	1-3'
Oenethera fruticosa	Sundrops	Plugs – 1 gal	1 plant/18" o.c.	Moist-dry	Yellow	
Penstemon digitalis	Smooth white	Plugs – 1 gal	1 plant/24" o.c.	Wet	White	2-3'
Penstemon hirsutus	Hairy beardtongue	Plugs – 1 gal	1 plant/18" o.c.	Dry	White	1-3'
Penstemon smallii	Beardtongue	Plugs – 1 gal	1 plant/18" o.c.	Moist	Purple	1-2'
Pycanthemum	Slender mountain mint	Plugs – 1 gal	1 plant/18" o.c.	Moist	White	1.5-2.5'
Ratibida piñata	Gray-headed	Plugs – 1 gal	1 plant/18" o.c.	Moist	Yellow	2-5'
Rudbeckia hirta	Black-eyed Susan	Plugs – 1 gal	1 plant/18" o.c.	Moist-dry	Yellow	3'
Salvia lyrata	Lyre-leaf sage	Plugs – 1 gal	1 plant/18" o.c.	Moist	Purple	1-2'
Solidago nemoralis	Gray goldenrod	Plugs – 1 gal.	1 plant/18" o.c.	Dry	Yellow	2'
Solidago rugosa	Rough-leaved goldenrod	Plugs – 1 gal.	1 plant/18" o.c.	Wet	Yellow	1-6'
Veronacastrum	Culver's root	Plugs – 1 gal.	1 plant/24" o.c.	Dry	White	3-6'
Veronia veboracensis	Tall ironweed	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Purple	3-4'

Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1

Popular Native Perennials for Bioretention – Shade						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Aquilegia canadensis	Wild columbine	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Pink	1-2.5'
Athyrium filix-femina	Lady Fern	1 gal.	1 plant/18" o.c.	Moist	Green	3'
Arisaema triphyllum	Jack-in-the-pulpit	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Green	1.5-2.5'
Arisaema dricontium	Green dragon	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Green	3'
Asarum canadense	Wild ginger	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Red-brown	0.5-1'
Aster cardifolius	Blue wood aster	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Blue	1-3'
Aster novae-angliae	New England aster	Plugs – 1 gal.	1 plant/24" o.c.	Moist-dry	Blue/ purple	3-4'
Aster oblongifolius	Aromatic Aster	Plugs – 1 gal.	1 plant/24" o.c.	Moist-dry	Blue/ purple	1.5-3'
Coreopsis major	Tickseed coreopsis	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Yellow	3'
Dryopteris marginalis	Shield Fern	1 gal.	1 plant/18" o.c.	Moist	Green	2-3'
Geranium maculatum	Wild geranium	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Pink	2'
Heuchera americana	Alumroot	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	1'
Iris cristata	Dwarf crested iris	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	4"
Lobelia siphilicata	Great blue lobelia	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Blue	1.5-3'
Lobelia cardinalis	Cardinal flower	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Red	2-4'
Mertensia virginica	Virginia bluebells	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Blue	1.5'
Osmunda cinnamomea	Cinnamon Fern	1 gal.	1 plant/24" o.c.	Wet-moist	Green	3-4'
Phlox diviricata	Blue phlox	Plugs – 1 gal.	1 plant/18" o.c.	moist	Blue	0.5-2'
Polemonium reptans	Jacob's ladder	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Blue	15"
Polystichum acrostichoides	Christmas fern	Plugs – 1 gal.	1 plant/24" o.c.	Moist-dry	Evergree n	2'
Stylophoru diphyllum	Wood poppy	Plugs – 1 gal.	1 plant/18" o.c.	Wet -moist	Yellow	1.5'

Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1.

Popular Native Grasses and Sedges for Bioretention						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Carex grayi	Gray's Sedge	1 gal.	1 plant/24" o.c.	Moist	Green	3'
Carex muskingumensis	Palm Sedge	1 gal.	1 plant/24" o.c.	Moist	Green	3'
Carex stricta	Tussock Sedge	1 gal.	1 plant/24" o.c.	Moist	Green	3-4'
Chasmanthium latifolium	Upland Sea Oats	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Green	4'
Equisetum hyemale	Horsetail	Plugs – 1 gal.	1 plant/18" o.c.	Wet	Green	3'
Juncus effesus	Soft Rush	Plugs – 1 gal.	1 plant/24" o.c.	Wet-dry	Green	4-6'
Muhlenbergia capallaris	Muhly Grass	1 gal.	1 plant/24" o.c.	Moist	Pink	3'
Panicum virgatum	Switchgrass	1-3 gal.	1 plant/48" o.c.	Moist-dry	Yellow	5-7'
Schizachyrium scoparium	Little Blue Stem	1 gal.	1 plant/24" o.c.	Moist-dry	Yellow	3'
Sporobolus heterolepsis	Prairie Dropseed	1 gal.	1 plant/24" o.c.	Moist-dry	Green	2-3'

Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1.

Popular Native Trees for Bioretention							
Latin Name	**Common Name**	**DT-FT**	**Light**	**Moisture**	**Notes**	**Flower Color**	**Height**
Acer rubrum	Red Maple	DT-FT	Sun-shade	Dry-wet	Fall color		50-70'
Acer saccharum	Sugar Maple		Sun-pt shade	Moist	Fall color		50-75'
Ameleanchier Canadensis	Serviceberry		Sun-pt shade	Moist-wet	Eatable berries	White	15-25'
Asimina triloba	Paw Paw		Sun-pt shade	Moist	Eatable fruits	Maroon	15-30'
Betula nigra	River Birch	FT	Sun-pt shade	Moist-wet	Exfoliating bark		40-70'
Carpinus caroliniana	Ironwood		Sun-pt shade	Moist		White	40-60'
Carya aquatica	Water Hickory	FT-DT	Sun	Moist	Fall color		35-50'
Cercus Canadensis	Redbud	DT	Sun-shade	Moist	Pea-like flowers, seed pods	Purple	20-30'
Chionanthus virginicus	Fringetree		Sun-pt shade	Moist	Panicled, fragrant flowers	White	12-20'
Cladratis lutea	Yellowwood	DT	Sun	Dry-moist	Fall color	White	30-45'
Cornus florida	Flowering Dogwood		Part shade	Moist	Red fruit, wildlife	White	15-30'
Ilex opaca	American Holly	DT	Sun-pt shade	Moist	Evergreen	White	30-50'
Liquidambar styraciflua	Sweetgum	DT-FT	Sun-pt shade	Dry-moist	Spiny fruit		60-100'
Magnolia virginiana	Sweetbay Magnolia		Sun-pt shade	Moist-wet	Evergreen	White	10-60'
Nyssa sylvatica	Black Gum		Sun-Shade	Moist	Fall color		35-50'
Oxydendrum arboretum	Sourwood		Sun-pt shade	Dry-moist	Wildlife	White	20-40'
Platanus occidentalis	Sycamore	FT	Sun-pt shade	Moist	White mottled bark		70-100'
Quercus bicolor	Swamp White Oak	DT	Sun-pt shade	Moist-wet	Acorns		50-60'
Quercus nuttalli	Nuttall Oak	DT	Sun	Dry-moist	Acorns		40-60'
Quercus lyrata	Overcup Oak	FT	Sun	Moist	Acorns		40-60'
Quercus shumardii	Shumard Oak	DT	Sun	Moist	Acorns		40-60'
Rhamnus caroliniana	Carolina Buckthorn		Sun	Moist	Black fruit		15-30'
Salix nigra	Black Willow	FT	Sun-pt shade	Moist-wet	White catkins	Yellow	40-60'
Ulmus americana	American Elm	DT-FT	Sun-pt shade	Moist			
Salix nigra	Black Willow	FT	Pt shade	Moist-wet	White catkins	Yellow	40-60'

Size: min. 2" caliper if not reforestation. DT: Drought Tolerant FT: Flood Tolerant
Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1.

Popular Native Shrubs for Bioretention								
Latin Name	**Common Name**	**D TF**	**Light**	**Moisture**	**Spacing (0 C)**	**Notes**	**Flower Color**	**Height**
Aronia arbutifolia	Red Chokeberry	FT	Sun-pt shade	Dry-wet	4'	Red berries, wildlife	White	6-12'
Buddleia davidii	Butterfly Bush	DT	Sun-pt shade	Dry-moist	4'	Non-native	Blue	5'
Callicarpa Americana	American Beautyberry	DT	Sun-pt shade	Dry-wet	5'	Showy purple fruit	Lilac	4-6'
Cephalanthus occidentalis	Button Bush	FT	Sun-shade	Moist-wet	5'	Attracts wildlife	White	6-12'
Clethra alnifolia	Sweet Pepper Bush		Sun-pt shade	Dry-moist	3'	Hummingbird	White	5-8'
Cornus amomum	Silky Dogwood		Sun-shade	Moist-wet	6'	Blue berries, wildlife	White	6-12'
Corylus americana	American Hazelnut		Sun-pt shade	Dry-moist	8'	Eatable nuts, wildlife	Yellow	8-15'
Hamemelis virginiana	Witch-hazel		Sun-pt shade	Dry-moist	8'	Winter bloom	Yellow	10'
Hibiscus moscheutos	Swamp Mallow	FT	Sun	Moist-wet	30"	Cold-hardy	White – red	4-7'
Hydrangea quercifolia	Oakleaf Hydrangea	DT	Pt shade – shade	Moist	4'	Winter texture	White	3-6'
Hypericum frondosum	Golden St. John's Wort	DT	Sun-pt shade	Dry-moist	30"	Semi-evergreen	Yellow	2-3'
Hypericum prolificum	Shrubby St. John's Wort	DT	Sun-pt shade	Dry-moist	3'	Semi-evergreen	Yellow	3'
Ilex decidua (dwarf var.)	Possumhaw Viburnum	DT	Sun-pt shade	Moist	4-6'	Red berries		6-14'
Ilex glabra	Inkberry	DT	Sun-pt shade	Moist-wet	3'	Evergreen		4-8'
Ilex verticillata	Winterberry Holly	FT	Sun-pt shade	Moist-wet	3'	Red berries		10'
Itea virginica	Virginia Sweetspire	DT FT	Sun-shade	Moist-wet	4'	Fall color	White	4-8'
Lindera benzoin	Spicebush	DT	Pt shade – shade	Moist-wet	8'	Butterflies, wildlife	Yellow	6-12'
Viburnum dentatum	Arrowwood Viburnum		Sun-shade	Dry-wet	6'	Wildlife	White	6-8'

Size: minimum 3 gal. container or equivalent. DT: Drought Tolerant FT: Flood Tolerant
This list provides plant species; there are multiple varieties within each species.
Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1.

APPENDIX 1-E
AS-BUILT REQUIREMENTS

A printer friendly version of this table can be found on the MWS Development Services website or by request.

Forebay Number:

	Design	As-Built
Top of Bank Elevation		
Top of Check Dam		
Bottom of Forebay		
Surface Area, SF		
Pretreatment Volume, CF		
ALL Elevation shall be NAVD88		

Bioretention Number:

	Design	As-Built
Treatment Volume (Tv), CF		
Surface Area, SF		
Top of Bank Elevation		
Emergency Spillway Elevation*		
Overflow (TOC) Elevation*		
(A) GIP Surface Elevation		
(B) Top of Stone Elevation		
Underdrain Invert*		
Outlet Elevation*		
(C) Subgrade Elevation		
* N/A if not required		
ALL Elevation shall be NAVD88		

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Urban Bioretention

Description: Urban bioretention is similar to traditional bioretention practices, except that the urban bioretention is fit into concrete-sided containers within urban landscapes, such as planter boxes or tree planters. Captured runoff is treated by filtration through an engineered soil medium, and is then either infiltrated into the subsoil or exfiltrated through an underdrain.

Advantages/Benefits:

- Reduced runoff volume
- Reduced peak discharge rate
- Reduced Total Suspended Solids (TSS)
- Reduced pollutant loading
- Reduced runoff temperature
- Groundwater recharge (if soils are sufficiently permeable)
- Habitat creation
- Enhanced site aesthetics
- Reduced heat island effect

Disadvantages/Limitations:

- Problems with installation can lead to failure
- Minimum 2 foot separation from groundwater and bedrock is required for applications without an impermeable bottom
- Suitable for pollution hotspots only with underdrain and liner

Selection Criteria:

40% Runoff Reduction Credit

Land Use Considerations:

- [X] **Residential**
- [X] **Commercial**
- [X] **Industrial**

Maintenance:

- Regular maintenance of landscaping to maintain healthy vegetative cover
- Irrigation when necessary during first growing season
- Periodic trash removal

[M] **Maintenance Burden**
L = Low   M = Moderate   H = High

SECTION 1: DESCRIPTION

Urban bioretention practices are similar in function to regular urban 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 (ROW), urban landscaping beds, tree planters, and plazas. Urban bioretention is not intended for large commercial areas. Urban bioretention is intended to be incorporated into small fragmented drainage areas such as shopping or pedestrian plazas within a larger urban development.

Urban bioretention features hard edges, often with vertical concrete sides, as contrasted with the more gentle earthen slopes of regular urban bioretention. If these practices are outside of the ROW, they may be open-bottomed, to allow some infiltration of runoff into the sub-grade, but they generally are served by an underdrain. Each urban bioretention variant is planted with a mix of trees, shrubs, and grasses as appropriate for its size and landscaping context.

SECTION 2: PERFORMANCE

The runoff reduction function of an urban bioretention area is described in **Table 2.1**.

Table 2.1. Runoff Volume Reduction Provided by Urban bioretention Basins

Stormwater Function	Level 1 Design
Runoff Volume Reduction (RR)	40%
Treatment Volume (Tv) Multiplier*	1.0

*Incorporated into LID Site Design Tool calculations
Sources: CSN (2008) and CWP (2007)

SECTION 3: TYPICAL DETAILS

See Appendix 1-B and 1-C for required standard notes and applicable details for use in construction plans.

SECTION 4: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Urban bioretention can be applied in most soils or topography, since runoff simply percolates through an engineered soil bed and can be returned to the stormwater system if the infiltration rate of the underlying soils is low. Key considerations with urban bioretention include the following:

Infiltration/Soils. Infiltration is a key component of Low Impact Development (LID) design. Infiltration testing may be required for some urban bioretention applications (see **Section 5.1**). Soil conditions do not constrain the use of urban bioretention but can affect the design requirements. Hydrologic Soil Groups (HSG) should be determined from NRCS soil data. For more information on soil types go to: http://websoilsurvey.nrcs.usda.gov/app/. Alternative HSG classifications will be considered when supporting reports from a licensed soil scientist or geotechnical engineer are provided.

Available Space. A prime advantage of urban bioretention is that it requires minimal additional space at a new development or redevelopment site, which can be important for tight sites or areas where land prices are high.

Accessibility. Urban bioretention facilities require periodic maintenance and must be accessible to various types of equipment. A path of travel for equipment no less than twelve feet in width with a maximum slope of 3:1 must be provided for the urban bioretention facility. The path of travel shall be along no less than 50% of the perimeter of the urban bioretention area and must be accessible by common equipment and vehicles at all times.

Subsurface Constraints. Urban bioretention perimeters typically consist of vertical constraints such as retaining walls, structures, or other impermeable barriers that comprise greater than 50% of the perimeter (≤50% see **GIP-01**). Urban bioretention subgrade shall always be separated from the water table and bedrock. Groundwater intersecting the filter bed can lead to possible groundwater contamination or failure of the urban bioretention facility. A separation distance of 2 feet is required between the bottom of the excavated urban bioretention area and the seasonally high ground water table and/or bedrock unless an impermeable liner is used.

Utilities. Designers must ensure that future tree canopy growth in the urban bioretention area will not interfere with existing overhead public utility lines. Public underground utilities and associated easements shall not be located within the urban bioretention footprint. Local utility design guidance shall be consulted in order to determine clearances required between stormwater infrastructure and other dry and wet utility lines. Private utilities should not be located within the urban bioretention area when possible.

Contributing Drainage Area. Urban bioretention is limited to 2,500 sq. ft. of drainage area. 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 planters or swales 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).

Hotspot Land Uses. Runoff from hotspot land uses should not be treated with infiltrating urban bioretention without appropriate pretreatment and MWS staff approval. For additional information on stormwater hotspots, please consult **Section 6.3**.

Floodplains. Urban bioretention areas shall be constructed outside the limits of the 100-year floodplain. Flood waters from the 100-year event or smaller shall be prohibited from entering the urban bioretention underdrain or overflow system.

Irrigation or Baseflow. The planned urban bioretention area shall not receive baseflow, chlorinated wash-water or other such non-stormwater flows, except for irrigation as necessary during the first growing season for the survival of plantings within the urban bioretention area (Consult the maintenance guidance outlined in **the main bioretention design specification (GIP-01) Section 9.2**).

Setbacks. To avoid the risk of seepage, a licensed professional engineer should be consulted to determine the appropriate setbacks necessary to prevent urban bioretention infiltration from compromising structural foundations or pavement.

Applications. Urban bioretention is typically used in medium to high density commercial, institutional and residential sites. It should be noted that special care must be taken to provide adequate pretreatment for urban bioretention cells in space-constrained high traffic areas. Typical locations for urban bioretention could include stormwater planters, green street swales, etc.

- **Green Street swales and planters** are installed in the sidewalk zone near the street where urban street trees are normally installed. ROW applications require an underdrain and an impermeable liner along the roadside to protect the roadway subgrade. This is a ROW application that requires MPW approval.

- **Stormwater 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 between buildings and roadways with liner protection.

SECTION 5: DESIGN CRITERIA

5.1 Soil Infiltration Rate Testing

If infiltration is utilized, one must measure the infiltration rate of subsoils at the subgrade elevation of the urban bioretention area. If the infiltration rate exceeds 0.5 inch per hour, an underdrain should not be utilized. If the infiltration rate of subsoils is greater than 0.1 inch per hour and less than or equal to 0.5 inch per hour, underdrains will be required. On-site soil infiltration rate testing procedures are outlined in **Appendix 1-A**. The number of soil tests varies base on the size of the urban bioretention area:

- < 1,000 ft^2 = 2 tests
- 1,000 – 10,000 ft^2 = 4 tests
- >10,000 ft^2 = 4 tests + 1 test for every additional 5,000 ft^2

A separation distance of 2 feet is required between the bottom of the excavated urban bioretention area and the seasonally high ground water table and/or bedrock, unless an impermeable liner is used.

5.2 Sizing of Urban Bioretention Practices

5.2.1 Stormwater Quality

Sizing of the surface area (SA) for urban bioretention practices is based on the computed Treatment Volume (T_v) of the contributing drainage area and the storage provided in the facility. The required surface area (in square feet) is computed as the Treatment Volume (in cubic feet) divided by the equivalent storage depth (in feet). The equivalent storage depth is computed as the depth of media, gravel, and surface ponding (in feet) multiplied by the accepted porosity (see **Table 2.2**). All layer depths shall be uniform with regard to surface area. The filter bed surface should generally be flat so the urban bioretention area fills up like a bathtub. A maximum surface slope of 3% is permitted. See **Section 5.5** for material specifications.

Table 2.2 Urban Bioretention Typical Section for Water Quality Calculations

Layer	Depth (inches)	Porosity Value (n)
Ponding	6	1.0
Surface Cover*	3	N/A
Media	24-48	0.25
Choker	3	0.40
Reservoir	9	0.40

* Cannot be used in De and surface area calculations.

The equivalent storage depth is therefore computed as:

Equation 1.1. Urban Bioretention Design Storage Depth

$$\text{Equivalent Storage Depth} = D_E = n_1(D_1) + n_2(D_2) + \cdots$$

$$D_E = (2 \text{ to } 4 \text{ ft.} \times 0.25) + (1 \text{ ft} \times 0.40) + (0.5 \times 1.0) = 1.4 \text{ to } 1.9 \text{ ft.}$$

Where n_1 and D_1 are for the first layer, etc.

Therefore, the Urban Bioretention Surface Area (SA) is computed as:

Equation 1.3. Urban Bioretention Design Surface Area

$$SA\ (sq.\ ft.) = (T_v - \text{the volume reduced by an upstream SCM}) / D_E$$

Where:

SA = Minimum surface area of bioretention filter (sq. ft.)

D_E = *Equivalent Storage Depth (ft.)*

T_v = Treatment Volume (cu. ft.) = [(1.0 in.)(R_v)(A)*3630]

5.2.2 Stormwater Quantity

It is recommended that rain events larger than the 1-inch storm bypass urban bioretention areas to prevent additional maintenance burden. However, if designed with sufficient volume and appropriate outlet structures, peak attenuation control may be provided by the urban bioretention area. Hydrologic calculations utilizing the SCS method may be necessary to demonstrate pre versus post peak flow rates.

Subsurface Storage. Designers may be able to create additional subsurface storage for flow attenuation by increasing the subsurface volume without necessarily increasing the urban bioretention footprint. Additional volume can be provided by increasing the depth of media, stone, or approved proprietary storage products. Subsurface storage will not be allowed without sufficient infiltration (see **Section 5.1**).

Adjusted CN. With infiltration rates greater than 0.5 inch per hour (see **Section 5.1**), the removal of volume by urban bioretention changes the runoff depth entering downstream flood control facilities. An approximate approach to accounting for the removal of volume is to calculate an "effective SCS curve number" (CN_{adj}), which is less than the actual curve number (CN). CN_{adj} can then be used in hydrologic calculations and in routing. This method is detailed in Volume 5 Section 3.2.5.

5.3 Pretreatment

Pretreatment facilities must always be used in conjunction with urban bioretention to remove floatables and sediment to prevent clogging and failure. Every green infrastructure practice must include pretreatment techniques, although the nature of pretreatment practices depends on the type of flow received. Pretreatment measures should be designed to evenly spread runoff across the entire width of the urban bioretention area. Several pretreatment measures are feasible, depending on the scale of the urban bioretention practice and whether it receives sheet flow, shallow concentrated flow or deeper concentrated flows. The number and type of acceptable pretreatment techniques needed for the types of receiving flow are found in **Table 2.3**.

Table 2.3. Required Pretreatment Elements for Infiltration Practices

Flow Type	
Point/Concentrated	*1 technique* • *Outlet protection* • *Proprietary structure (such as a trash rack, MWS approval required)*
Sheet	*Gravel diaphragm*
Upstream GIP	*Outlet protection required at upstream GIP outfall*

5.4 Conveyance and Overflow

An overflow structure should always be incorporated into on-line designs to safely convey larger storms through the urban bioretention area. Common overflow systems within urban bioretention practices consist of an outlet structure(s) and/or emergency spillway in compliance with the Stormwater Management Manual, Volume 2, Section 8.

5.5 Urban Bioretention Material Specifications

Table 2.4 outlines the standard material specifications used to construct urban bioretention areas.

Table 2.4 Bioretention Material Specifications		
Material	**Specification**	**Notes**
Mulch Layer	• Shredded hardwood • Hardwood bark • River stone • Coir or jute matting	Lay a 3-inch layer on the surface of the filter bed in order to suppress weed growth & prevent erosion. Stone shall not comprise more than 50% of the surface area.
Filter Media Composition	• 70% - 85% sand; • 10%-30% silt + clay, with clay ≤ 10%; and • 5% to 10% organic matter	The volume of filter media based on 110% of the plan volume, to account for settling or compaction. Minimum media infiltration rate 1 in/hr. Contact staff for testing procedures.
Geotextile	Use a non-woven geotextile fabric with a flow rate of > 110 gal./min./ft^2 (e.g., Geotex 351 or equivalent)	Apply only to the sides and above the underdrain (2'-4' wide strip). AASHTO M288-06, ASTM D4491 & D4751
Choker Layer	#8 or #89 clean washed stone	Meet TDOT Construction Specifications.
Reservoir Layer	#57 clean washed stone	Meet TDOT Construction Specifications.
Underdrain	6-inch dual wall HDPE or SDR 35 PVC pipe with 3/8-inch perforations at 6 inches on center	AASHTO M 252 Place perforated pipe at base of reservoir layer.
Cleanout	6-inch SDR 35 PVC pipe with vented cap	Provide cleanouts at the upper end of the underdrain.
Observation Well	6-inch SDR 35 PVC pipe with vented cap and anchor plate	Number of wells equals the number of test pits required for infiltration testing (see Appendix 2-A)

5.6 Urban Bioretention Planting Plans

A landscaping plan must be provided for each urban bioretention area. Minimum plan elements shall include the proposed planting plan for the surface area of the urban bioretention, the list of planting stock, sources of plant species, sizes of plants, and the planting sequence along with post-nursery care and initial maintenance requirements. The planting plan must address 100% of the planting area and achieve a surface area coverage of at least 75% in the first two years. Native plant species are preferred over non-native species, but some ornamental species may be used for landscaping effect if they are not aggressive or invasive. **Appendix 1-D** lists native plant species suitable for use in urban bioretention. Landscaping in the ROW should be designed to limit visual obstructions for pedestrian and vehicular traffic.

The planting plan must be prepared by a qualified Landscape Architect. The Landscape Architect shall certify the planting plan with certification statement, located on the urban bioretention planting plan. Standard certification statement can be found in **Appendix 2-B**.

SECTION 6: SPECIAL CASE DESIGN ADAPTATIONS

6.1 Shallow Bedrock and Groundwater Connectivity

Many parts of Nashville have shallow bedrock, which can constrain the application of urban bioretention areas (utilizing infiltration). In such settings, other GIPs may be more applicable. For more information on bedrock depths download the GIS data set from: http://water.usgs.gov/GIS/metadata/usgswrd/XML/regolith.xml.

6.2 Karst

Karst regions are found in much of Middle Tennessee, which complicates both land development and stormwater design. Infiltrative practices shall not be used in any area with a high risk of sinkhole formation. Urban bioretention areas must use an impermeable liner in these areas.

6.3 Hotspots

Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk for spills, leaks or illicit discharges. Urban Bioretention designs utilizing infiltration shall not be used in any area with a hotspot designation without appropriate pretreatment, impermeable barriers, and MWS staff approval. Designs that meet separation distance requirements (2 feet) and possess an impermeable bottom liner and an underdrain are suited for certain hotspots. Staff may also require additional treatment for runoff from hotspots.

SECTION 7: CONSTRUCTION

7.1 Construction

Construction Stage Erosion and Sediment Controls. Urban bioretention areas should be fully protected by silt fence and construction fencing to prevent sedimentation and compaction. Ideally, urban bioretention should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment.

Excavation. The proposed site should be checked for existing utilities prior to any excavation. It is very important to minimize compaction of both the base of the urban bioretention area and the required backfill. When possible, excavators should work from the sides of the urban bioretention area to remove original soil. Compaction will significantly contribute to design failure.

7.2 Urban Bioretention Installation

Construction should take place during appropriate weather conditions. The following is a typical construction sequence to properly install an urban bioretention basin. These steps may be modified to reflect different urban bioretention applications or expected site conditions:

Step 1. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area 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 urban 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 2. Ensure that the entire contributing drainage area has been stabilized prior to urban bioretention construction. Otherwise, use EPSC measures as outlined in **Section 7.1**.

Step 3. Excavation of the urban bioretention area should follow the guidelines found in **Section 7.1**.

Step 4. It may be necessary to rip the bottom soils to a depth of 6 to 12 inches to promote greater infiltration.

Step 5. Install all layers, components, and landscaping of the urban bioretention per plans. Media shall be tested per MWS standards. Irrigate plantings as needed.

Step 6. Conduct the final construction inspection (see **Section 8**). Then log the GPS coordinates for each urban bioretention facility and submit them to MWS.

SECTION 8: AS-BUILT REQUIREMENTS

After the urban bioretention area has been constructed, the owner/developer must have an as-built certification of the urban bioretention area conducted by a registered Professional Engineer. The as-built certification verifies that the GIP was installed per the approved plan. The following items shall be provided in addition to the as-built requirements found in SWMM Volume 1.

1. Landscape Architect letter certifying that the SCM plantings have been installed in general conformance with the approved grading plans and, with proper maintenance, should achieve 75% coverage within the first two years.
2. The Engineer shall include a copy of the GIP summary table found in Appendix 2-E.
3. Supporting documents such as invoices, photos, and media test results should be included in the submittal package.

SECTION 9: MAINTENANCE

Routine operation and maintenance are essential to gain public acceptance of highly visible urban bioretention areas. Weeding, pruning, the removal and replacement of dead vegetation 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. Maintenance shall be the responsibility of the property owner as outlined in Volume 1, Appendix C.

To ensure proper performance, installers 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 **the main bioretention design specification (GIP-01)**.

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

The following is a list of some community and environmental concerns that may arise when infiltration practices are proposed:

Nuisance Conditions. Poorly designed infiltration practices can create potential nuisance problems such as basement flooding, poor yard drainage and standing water. In most cases, these problems can be minimized through proper adherence to the setback, soil testing and pretreatment requirements outlined in this specification.

Mosquito Risk. Infiltration practices have some potential to create conditions favorable to mosquito breeding, if they clog and have standing water for extended periods. Proper installation and maintenance of the urban bioretention area will prevent these conditions from occurring.

Figure 2.1 Portland State University street planters.
(Photo: Martina Keefe)

Figure 2.2 Deaderick Street planters.

SECTION 11: REFERENCES

Chesapeake Stormwater Network (CSN). 2008. *Technical Bulletin 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed.* Version 1.0. Baltimore, MD. Available online at: http://www.chesapeakestormwater.net/all-things-stormwater/stormwater-guidance-for-karst-terrain-in-the-chesapeake-bay.html

CWP. 2007. *National Pollutant Removal Performance Database, Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection. 2006. *Urban Watershed Forestry Manual. Part 2: Conserving and Planting Trees at Development Sites.* Ellicott City, MD. Available online at: http://www.cwp.org/forestry/index.htm

City of Portland. Bureau of Environmental Services. (Portland BES). 2004. *Portland Stormwater Management Manual.* Portland, OR. http://www.portlandonline.com/bes/index.cfm?c=dfbcc

City of Portland. Bureau of Environmental Services. (Portland BES). 2011. *Stormwater Management Manual Typical Details.* Portland, OR. http://www.portlandonline.com/bes/index.cfm?c=47963

Credit Valley Conservation. 2008. *Credit River Stormwater Management Manual.* Mississauga, Ontario.

Northern Virginia Regional Commission. 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook.* Fairfax, Virginia

Saxton, K.E., W.J. Rawls, J.S. Romberger, and R.I. Papendick. 1986. "Estimating generalized soil-water characteristics from texture." *Soil Sci. Soc. Am. J.* 50(4):1031-1036.

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban stormwater retrofit practices.* Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

VADCR. 2010. *Stormwater Design Specification No. 9,* Appendix 9-A: Urban bioretention / Stormwater Planters / Expanded Tree Planters / Stormwater Curb Extensions, version 1.7. Virginia Department of Conservation and Recreation.

VADCR. 2013. Stormwater Design Specification No. 9, *Appendix 9-A: Urban bioretention / Stormwater Planters / Expanded Tree Planters / Stormwater Curb Extensions, version 1.7. Virginia Department of Conservation and Recreation.*

APPENDIX 2-A
INFILTRATION SOIL TESTING PROCEDURES

I. Test Pit/Boring Procedures

1. The number of required test pits or standard soil borings is based on proposed infiltration area:
   - < 1,000 ft^2 = 2 tests
   - 1,000 – 10,000 ft^2 = 4 tests
   - >10,000 ft^2 = 4 tests + 1 test for every additional 5,000 ft^2
2. The location of each test pit or standard soil boring should correspond to the location of the proposed infiltration area and be performed in in situ soils.
3. Excavate each test pit or penetrate each standard soil boring to a depth at least 2 feet below the bottom of the proposed infiltration area.
4. If the groundwater table is located within 2 feet of the bottom of the proposed facility, determine the depth to the groundwater table immediately upon excavation and again 24 hours after excavation is completed.
5. Determine the USDA or Unified Soil Classification system textures at the bottom of the proposed infiltration area and at a depth that is 2 feet below the bottom. All soil horizons should be classified and described.
6. If bedrock is located within 2 feet of the bottom of the proposed infiltration area, determine the depth to the bedrock layer.
7. Test pit/soil boring stakes should be left in the field to identify where soil investigations were performed.

II. Infiltration Testing Procedures

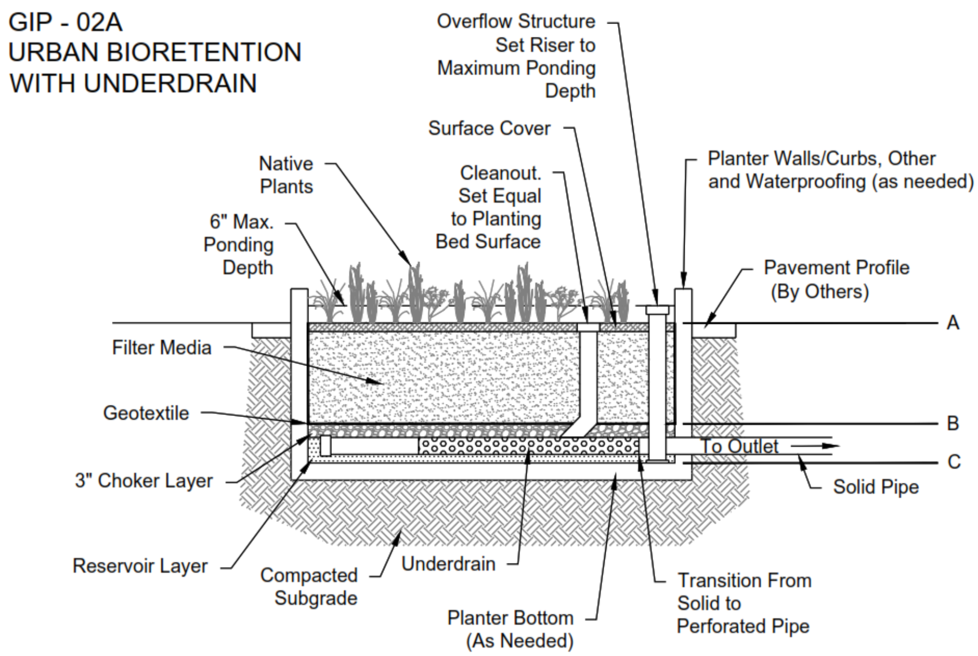
1. The number of required infiltration tests is based on proposed infiltration area:
   - < 1,000 ft^2 = 2 tests
   - 1,000 – 10,000 ft^2 = 4 tests
   - >10,000 ft^2 = 4 tests + 1 test for every additional 5,000 ft^2
2. The location of each infiltration test should correspond to the location of the proposed infiltration area.
3. Install a test casing (e.g., a rigid, 4 to 6-inch diameter pipe) to a depth 2 feet below the bottom of the proposed infiltration area. Record the testing elevation.
4. Remove all loose material from the sides of the test casing and any smeared soil material from the bottom of the test casing to provide a natural soil interface into which water may percolate. If desired, a 2-inch layer of coarse sand or fine gravel may be placed at the bottom of the test casing to prevent clogging and scouring of the underlying soils. Fill the test casing with clean water to a depth of 2 feet, and allow the underlying soils to presoak for 24 hours.
5. After 24 hours, refill the test casing with another 2 feet of clean water and measure the drop in water level within the test casing after one hour. Repeat the procedure three (3) additional times by filling the test casing with clean water and measuring the drop in water level after one hour. A total of four (4) observations must be completed.
6. The infiltration rate of the underlying soils may be reported either as the average of all four observations or the value of the last observation. The infiltration rate shall be reported in terms of inches per hour along with the elevations and locations of the test pits. Locations shall be shown on site map.
7. Infiltration testing may be performed within an open test pit or a standard soil boring. After infiltration testing is completed, the test casing should be removed, and the test pit or soil boring should be backfilled and restored.

APPENDIX 2-B
STANDARD NOTES

Required Urban bioretention Notes:

- Contractor, Engineer, or Owners Representative shall notify MWS NPDES staff at least 48 hours prior to the installation of the planting soil filter bed. At the completion of installation, the above referenced person will collect one sample per urban bioretention bed for analysis and confirmation of the soil characteristics as defined by GIP-01. Media testing not required when using a certified media product.
- I hereby certify that this urban bioretention planting plan is in keeping with the requirements listed in GIP-02 Section 5.6. Only native species and/or non-invasive species of plants were used in the design of this urban bioretention planting plan. This plan will achieve at least 75% surface area coverage within the first two years.
- Vehicular and equipment traffic shall be prohibited in an infiltrating urban bioretention area to prevent compaction and sediment deposition.

APPENDIX 2-C
STANDARD DETAILS



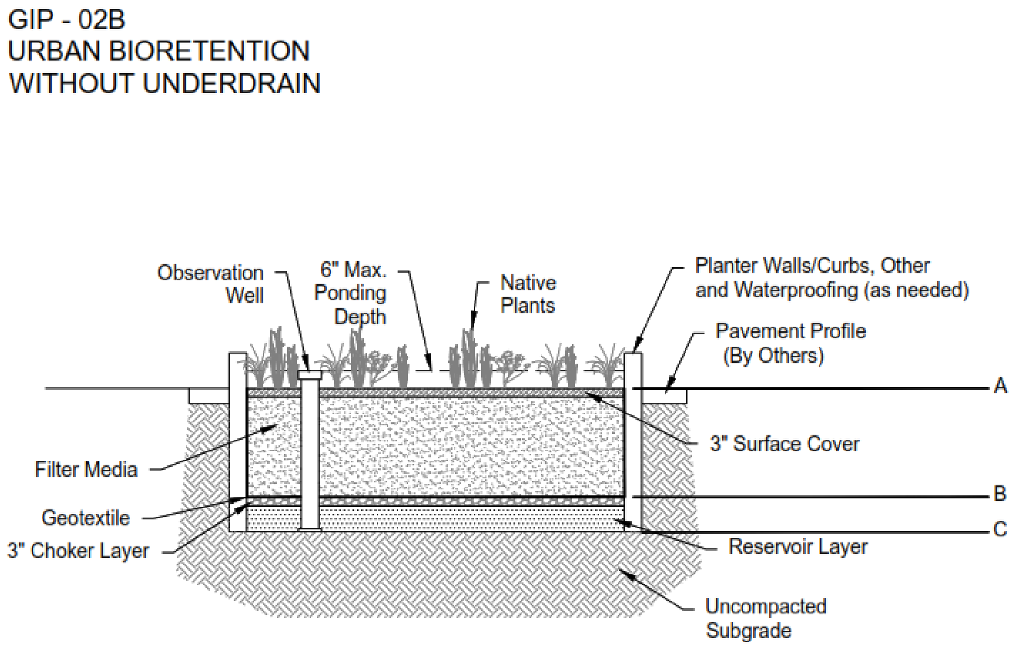


Figure 2.3. Design Details

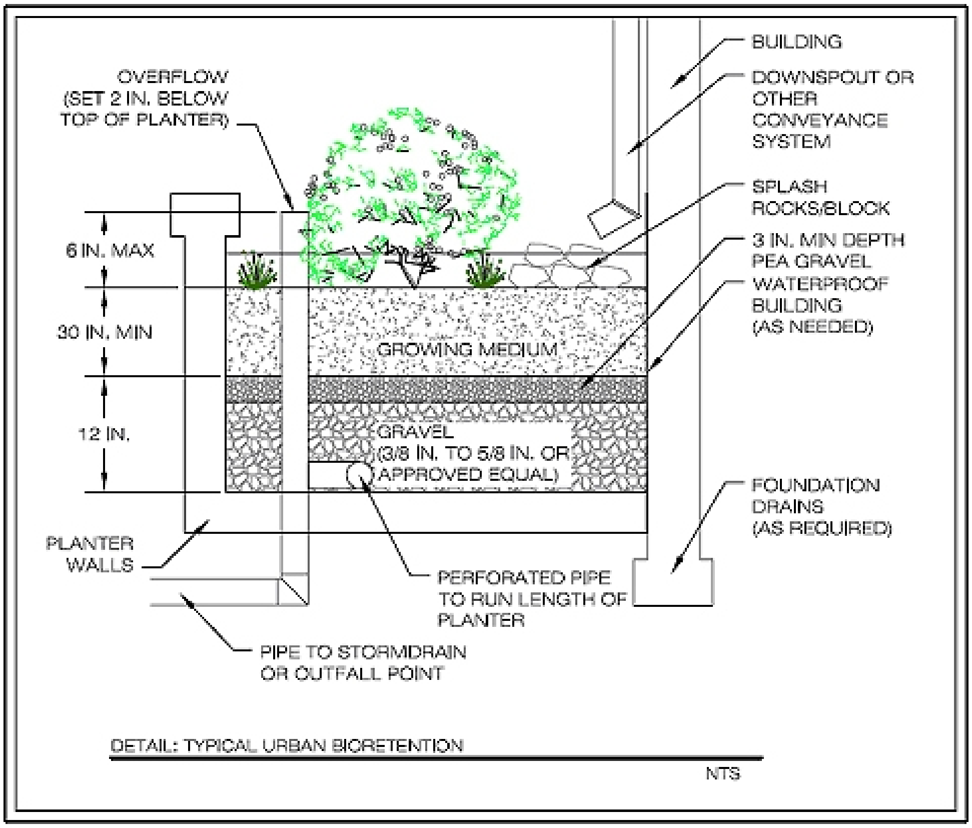


Figure 2.4. Stormwater Planter Cross-Section (source: VADCR, 2010)

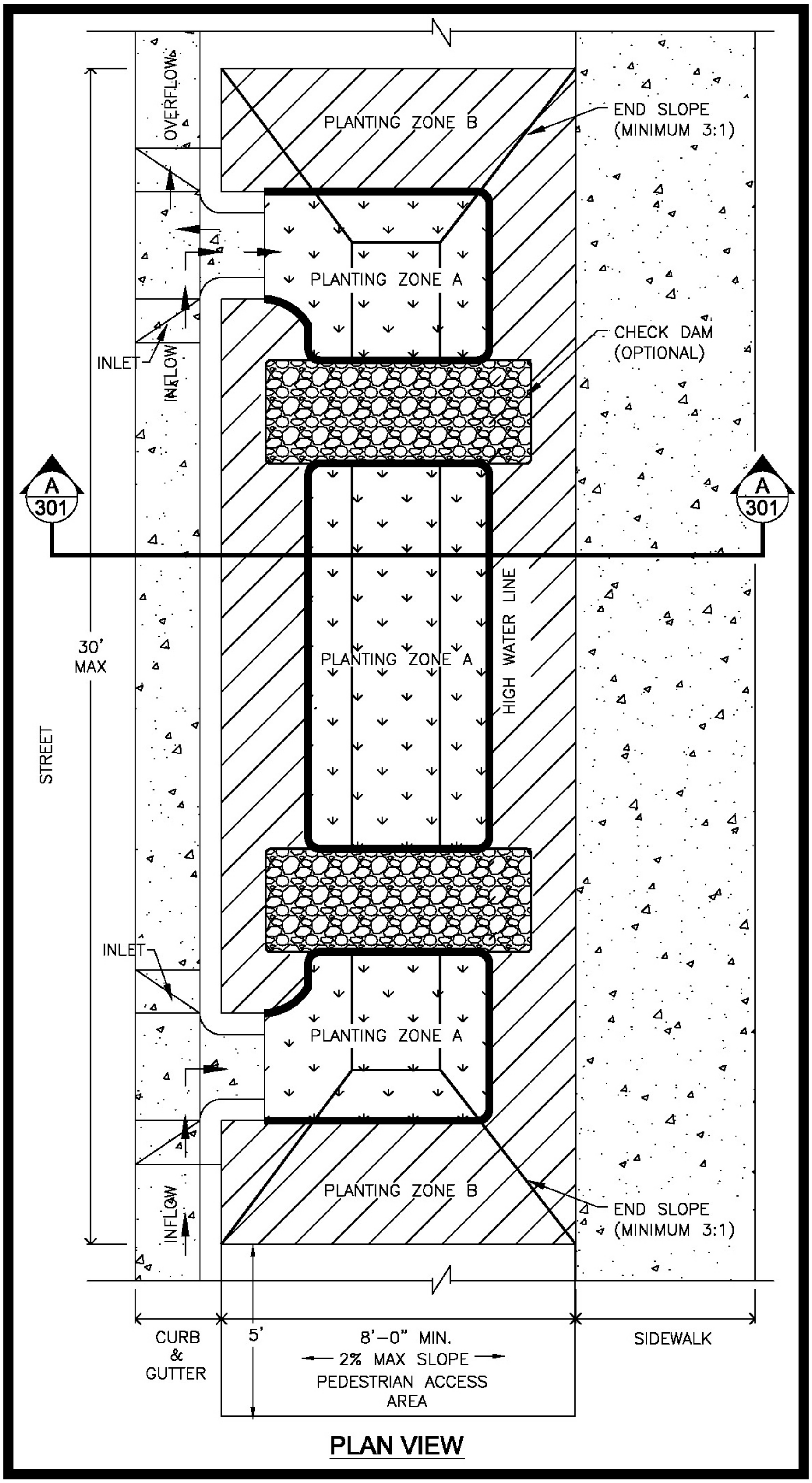


Figure 2.5. Green Streets Swale Plan View (source: Portland, 2011)

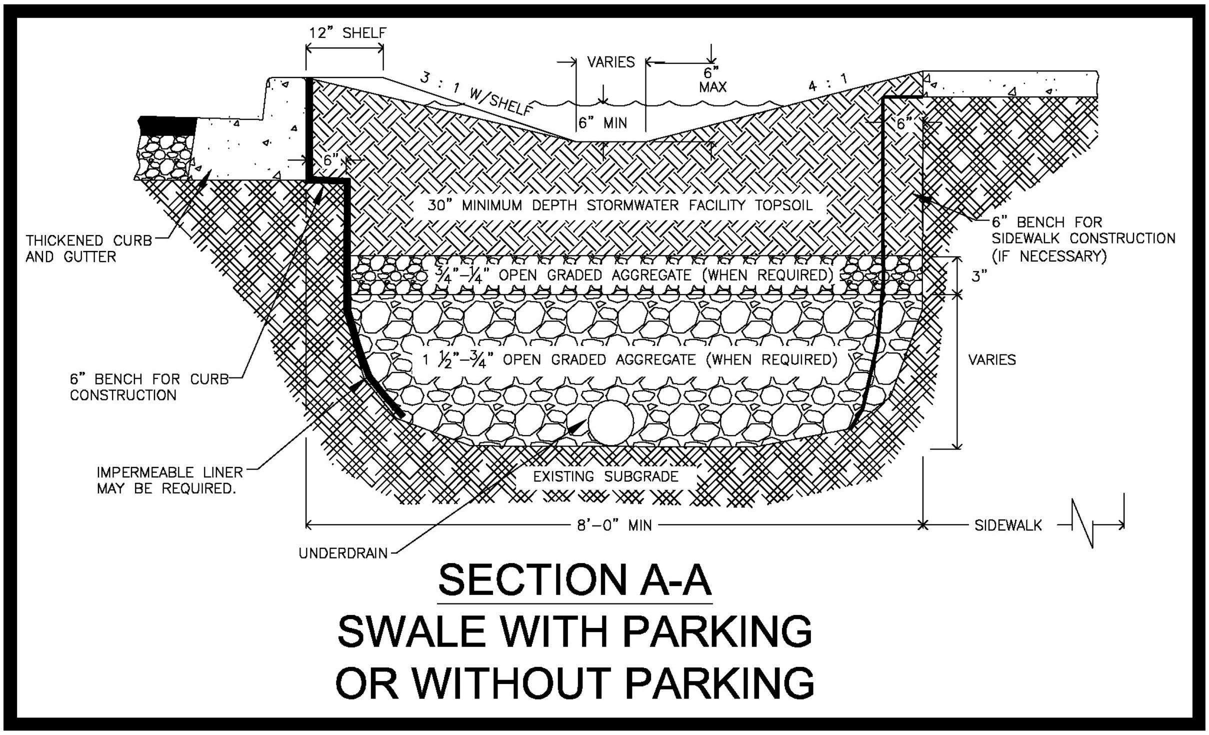


Figure 2.6. Green Streets Swale Section View (source: Portland, 2011)

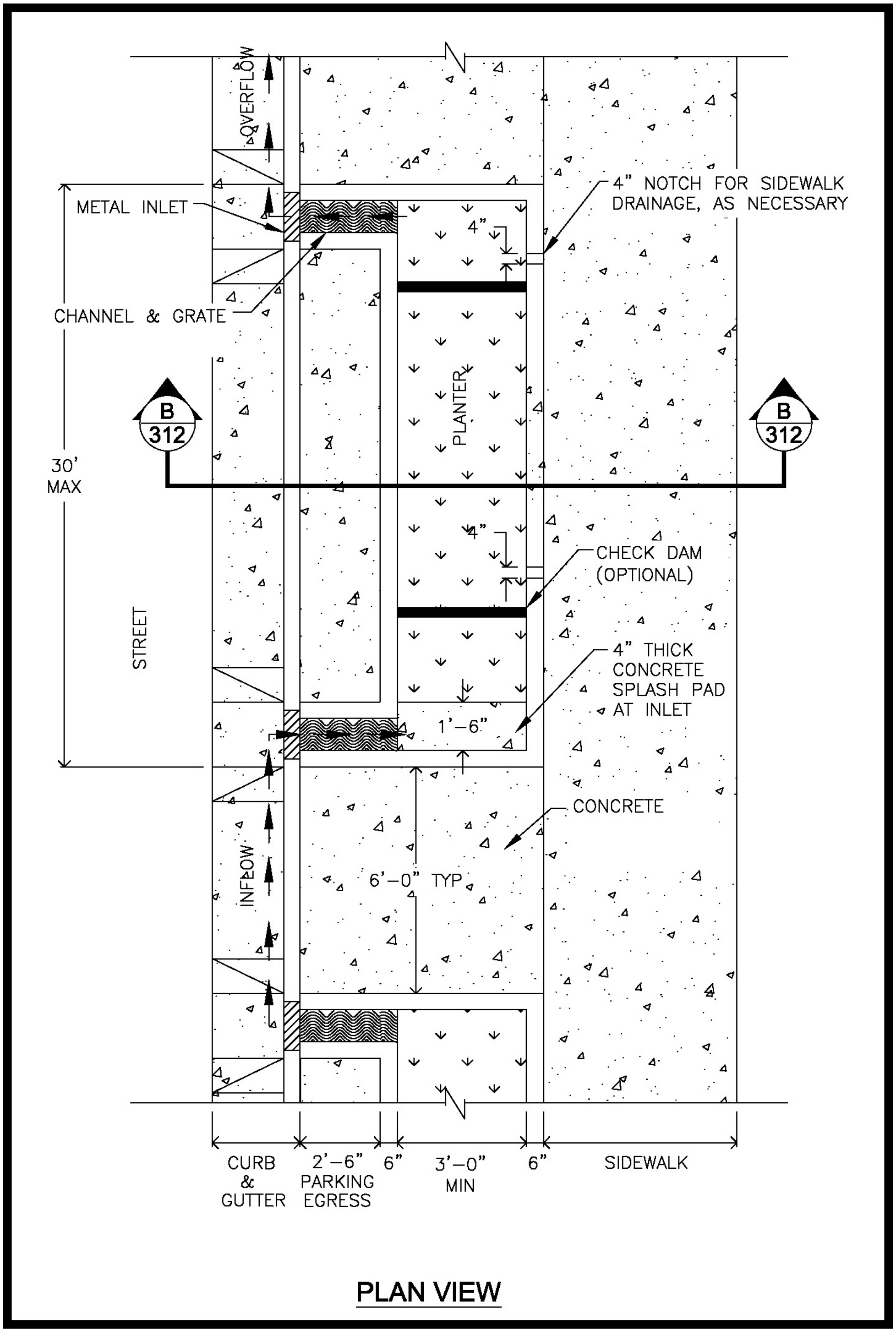


Figure 2.7. Green Streets Planter Plan View With Parking (source: Portland, 2011)

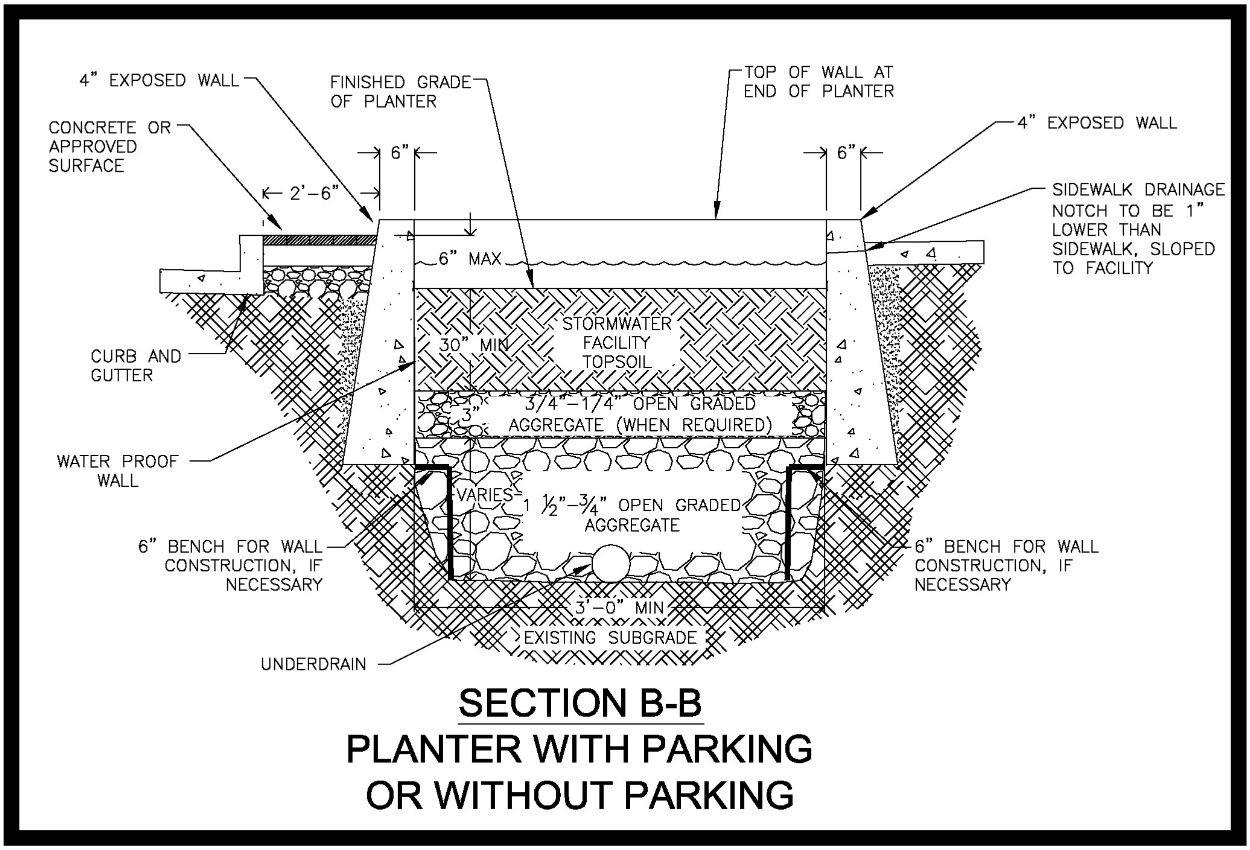


Figure 2.8. Green Streets Planter Section View With or Without Parking (source: Portland, 2011)

APPENDIX 2-D
NATIVE PLANTINGS

Popular Native Perennials for Urban Bioretention – Full Sun						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Asclepias incarnate	Marsh milkweed	Plugs – 1 gal.	1 plant/24" o.c.	Wet	Pink	3-4'
Asclepias purpurescens	Purple milkweed	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Purple	3'
Asclepias syriaca	Common milkweed	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Orange	2-5'
Asclepias tuberosa	Butterfly milkweed	Plugs – 1 gal.	1 plant/18" o.c.	Dry-moist	Orange	2'
Asclepias verdis	Green milkweed	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Green	2'
Asclepias verdicillata	Whorled milkweed	Plugs – 1 gal.	1 plant/18" o.c.	Moist	White	2.5'
Aster laevis	Smooth aster	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Blue	2-4'
Aster novae-angliae	New England aster	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Blue	2-5'
Aster sericeus	Silky aster	Plugs – 1 gal.	1 plant/18" o.c.	Dry	Purple	1-2'
Chamaecrista fasciculata	Partridge pea	Plugs – 1 gal.	1 plant/18" o.c.	Dry	Yellow	1-2'
Conoclinium coelestinum	Mist flower	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Blue	1-2'
Coreopsis lanceolata	Lance-leaf coreopsis	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Yellow	6-8'
Echinacea pallida	Pale purple coneflower	Plugs – 1 gal.	1 plant/18" o.c.	Dry	Purple	2-3'
Echinacea purpurea	Purple coneflower	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	3-4'
Eupatorium perfoliatum	Boneset	Plugs – 1 gal.	1 plant/24" o.c.	Wet	White	3-5'
Eupatorium purpureum	Sweet Joe-Pye Weed	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Purple	3-6'
Iris virginica	Flag Iris	Plugs – 1 gal.	1 plant/18" o.c.	Moist-Wet	Blue	2'
Liatris aspera	Rough blazingstar	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	2-5'
Liatris microcephalla	Small-headed blazingstar	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	3'
Liatris spicata	Dense blazingstar	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Purple	1.5'
Liatris squarrulosa	Southern blazingstar	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	2-6'
Lobelia cardinalis	Cardinal flower	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Red	2-4'
Monarda didyma	Bee balm	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Red	3'
Monarda fistulosa	Wild bergamot	Plugs – 1 gal	1 plant/18" o.c.	Moist	Purple	1-3'
Oenethera fruticosa	Sundrops	Plugs – 1 gal	1 plant/18" o.c.	Moist-dry	Yellow	
Penstemon digitalis	Smooth white	Plugs – 1 gal	1 plant/24" o.c.	Wet	White	2-3'
Penstemon hirsutus	Hairy beardtongue	Plugs – 1 gal	1 plant/18" o.c.	Dry	White	1-3'
Penstemon smallii	Beardtongue	Plugs – 1 gal	1 plant/18" o.c.	Moist	Purple	1-2'
Pycanthemum tenuifolium	Slender mountain mint	Plugs – 1 gal	1 plant/18" o.c.	Moist	White	1.5-2.5'
Ratibida piñata	Gray-headed coneflower	Plugs – 1 gal	1 plant/18" o.c.	Moist	Yellow	2-5'
Rudbeckia hirta	Black-eyed Susan	Plugs – 1 gal	1 plant/18" o.c.	Moist-dry	Yellow	3'
Salvia lyrata	Lyre-leaf sage	Plugs – 1 gal	1 plant/18" o.c.	Moist	Purple	1-2'
Solidago nemoralis	Gray goldenrod	Plugs – 1 gal.	1 plant/18" o.c.	Dry	Yellow	2'
Solidago rugosa	Rough-leaved goldenrod	Plugs – 1 gal.	1 plant/18" o.c.	Wet	Yellow	1-6'
Veronacastrum virginicum	Culver's root	Plugs – 1 gal.	1 plant/24" o.c.	Dry	White	3-6'
Veronia veboracensis	Tall ironweed	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Purple	3-4'

Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1

Popular Native Perennials for Urban Bioretention – Shade						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Aquilegia canadensis	Wild columbine	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Pink	1-2.5'
Athyrium filix-femina	Lady Fern	1 gal.	1 plant/18" o.c.	Moist	Green	3'
Arisaema triphyllum	Jack-in-the-pulpit	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Green	1.5-2.5'
Arisaema dricontium	Green dragon	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Green	3'
Asarum canadense	Wild ginger	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Red-brown	0.5-1'
Aster cardifolius	Blue wood aster	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Blue	1-3'
Aster novae-angliae	New England aster	Plugs – 1 gal.	1 plant/24" o.c.	Moist-dry	Blue/ purple	3-4'
Aster oblongifolius	Aromatic Aster	Plugs – 1 gal.	1 plant/24" o.c.	Moist-dry	Blue/ purple	1.5-3'
Coreopsis major	Tickseed coreopsis	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Yellow	3'
Dryopteris marginalis	Shield Fern	1 gal.	1 plant/18" o.c.	Moist	Green	2-3'
Geranium maculatum	Wild geranium	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Pink	2'
Heuchera americana	Alumroot	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	1'
Iris cristata	Dwarf crested iris	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	4"
Lobelia siphilicata	Great blue lobelia	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Blue	1.5-3'
Lobelia cardinalis	Cardinal flower	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Red	2-4'
Mertensia virginica	Virginia bluebells	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Blue	1.5'
Osmunda cinnamomea	Cinnamon Fern	1 gal.	1 plant/24" o.c.	Wet-moist	Green	3-4'
Phlox divericata	Blue phlox	Plugs – 1 gal.	1 plant/18" o.c.	moist	Blue	0.5-2'
Polemonium reptans	Jacob's ladder	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Blue	15"
Polystichum acrostichoides	Christmas fern	Plugs – 1 gal.	1 plant/24" o.c.	Moist-dry	Evergreen	2'
Stylophoru diphyllum	Wood poppy	Plugs – 1 gal.	1 plant/18" o.c.	Wet -moist	Yellow	1.5'

Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1.

Popular Native Grasses and Sedges for Urban Bioretention						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Carex grayi	Gray's Sedge	1 gal.	1 plant/24" o.c.	Moist	Green	3'
Carex muskingumensis	Palm Sedge	1 gal.	1 plant/24" o.c.	Moist	Green	3'
Carex stricta	Tussock Sedge	1 gal.	1 plant/24" o.c.	Moist	Green	3-4'
Chasmanthium latifolium	Upland Sea Oats	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Green	4'
Equisetum hyemale	Horsetail	Plugs – 1 gal.	1 plant/18" o.c.	Wet	Green	3'
Juncus effesus	Soft Rush	Plugs – 1 gal.	1 plant/24" o.c.	Wet-dry	Green	4-6'
Muhlenbergia capallaris	Muhly Grass	1 gal.	1 plant/24" o.c.	Moist	Pink	3'
Panicum virgatum	Switchgrass	1-3 gal.	1 plant/48" o.c.	Moist-dry	Yellow	5-7'
Schizachyrium scoparium	Little Blue Stem	1 gal.	1 plant/24" o.c.	Moist-dry	Yellow	3'
Sporobolus heterolepsis	Prairie Dropseed	1 gal.	1 plant/24" o.c.	Moist-dry	Green	2-3'

Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1.

Popular Native Trees for Urban Bioretention							
Latin Name	**Common Name**	**DT-FT**	**Light**	**Moisture**	**Notes**	**Flower Color**	**Height**
Acer rubrum	Red Maple	DT-FT	Sun-shade	Dry-wet	Fall color		50-70'
Acer saccharum	Sugar Maple		Sun-pt shade	Moist	Fall color		50-75'
Ameleanchier Canadensis	Serviceberry		Sun-pt shade	Moist-wet	Eatable berries	White	15-25'
Asimina triloba	Paw Paw		Sun-pt shade	Moist	Eatable fruits	Maroon	15-30'
Betula nigra	River Birch	FT	Sun-pt shade	Moist-wet	Exfoliating bark		40-70'
Carpinus caroliniana	Ironwood		Sun-pt shade	Moist		White	40-60'
Carya aquatica	Water Hickory	FT-DT	Sun	Moist	Fall color		35-50'
Cercus Canadensis	Redbud	DT	Sun-shade	Moist	Pea-like flowers, seed pods	Purple	20-30'
Chionanthus virginicus	Fringetree		Sun-pt shade	Moist	Panicled, fragrant flowers	White	12-20'
Cladratis lutea	Yellowwood	DT	Sun	Dry-moist	Fall color	White	30-45'
Cornus florida	Flowering Dogwood		Part shade	Moist	Red fruit, wildlife	White	15-30'
Ilex opaca	American Holly	DT	Sun-pt shade	Moist	Evergreen	White	30-50'
Liquidambar styraciflua	Sweetgum	DT-FT	Sun-pt shade	Dry-moist	Spiny fruit		60-100'
Magnolia virginiana	Sweetbay Magnolia		Sun-pt shade	Moist-wet	Evergreen	White	10-60'
Nyssa sylvatica	Black Gum		Sun-Shade	Moist	Fall color		35-50'
Oxydendrum arboretum	Sourwood		Sun-pt shade	Dry-moist	Wildlife	White	20-40'
Platanus occidentalis	Sycamore	FT	Sun-pt shade	Moist	White mottled bark		70-100'
Quercus bicolor	Swamp White Oak	DT	Sun-pt shade	Moist-wet	Acorns		50-60'
Quercus nuttalli	Nuttall Oak	DT	Sun	Dry-moist	Acorns		40-60'
Quercus lyrata	Overcup Oak	FT	Sun	Moist	Acorns		40-60'
Quercus shumardii	Shumard Oak	DT	Sun	Moist	Acorns		40-60'
Rhamnus caroliniana	Carolina Buckthorn		Sun	Moist	Black fruit		15-30'
Salix nigra	Black Willow	FT	Sun-pt shade	Moist-wet	White catkins	Yellow	40-60'
Ulmus americana	American Elm	DT-FT	Sun-pt shade	Moist			
Salix nigra	Black Willow	FT	Pt shade	Moist-wet	White catkins	Yellow	40-60'

Size: min. 2" caliper if not reforestation. DT: Drought Tolerant FT: Flood Tolerant
Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1.

Popular Native Shrubs for Urban bioretention								
Latin Name	**Common Name**	**DT-FT**	**Light**	**Moisture**	**Spacing (0 C)**	**Notes**	**Flower Color**	**Height**
Aronia arbutifolia	Red Chokeberry	FT	Sun-pt shade	Dry-wet	4'	Red berries, wildlife	White	6-12'
Buddleia davidii	Butterfly Bush	DT	Sun-pt shade	Dry-moist	4'	Non-native	Blue	5'
Callicarpa Americana	American Beautyberry	DT	Sun-pt shade	Dry-wet	5'	Showy purple fruit	Lilac	4-6'
Cephalanthus occidentalis	Button Bush	FT	Sun-shade	Moist-wet	5'	Attracts wildlife	White	6-12'
Clethra alnifolia	Sweet Pepper Bush		Sun-pt shade	Dry-moist	3'	Hummingbird	White	5-8'
Cornus amomum	Silky Dogwood		Sun-shade	Moist-wet	6'	Blue berries, wildlife	White	6-12'
Corylus americana	American Hazelnut		Sun-pt shade	Dry-moist	8'	Eatable nuts, wildlife	Yellow	8-15'
Hamemelis virginiana	Witch-hazel		Sun-pt shade	Dry-moist	8'	Winter bloom	Yellow	10'
Hibiscus moscheutos	Swamp Mallow	FT	Sun	Moist-wet	30"	Cold-hardy	White – red	4-7'
Hydrangea quercifolia	Oakleaf Hydrangea	DT	Pt shade – shade	Moist	4'	Winter texture	White	3-6'
Hypericum frondosum	Golden St. John's Wort	DT	Sun-pt shade	Dry-moist	30"	Semi-evergreen	Yellow	2-3'
Hypericum prolificum	Shrubby St. John's Wort	DT	Sun-pt shade	Dry-moist	3'	Semi-evergreen	Yellow	3'
Ilex decidua (dwarf var.)	Possumhaw Viburnum	DT	Sun-pt shade	Moist	4-6'	Red berries		6-14'
Ilex glabra	Inkberry	DT	Sun-pt shade	Moist-wet	3'	Evergreen		4-8'
Ilex verticillata	Winterberry Holly	FT	Sun-pt shade	Moist-wet	3'	Red berries		10'
Itea virginica	Virginia Sweetspire	DTFT	Sun-shade	Moist-wet	4'	Fall color	White	4-8'
Lindera benzoin	Spicebush	DT	Pt shade – shade	Moist-wet	8'	Butterflies, wildlife	Yellow	6-12'
Viburnum dentatum	Arrowwood Viburnum		Sun-shade	Dry-wet	6'	Wildlife	White	6-8'

Size: minimum 3 gal. container or equivalent. DT: Drought Tolerant FT: Flood Tolerant
This list provides plant species; there are multiple varieties within each species.
Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1.

Popular Plants Suitable for Tree Planters in Metro Nashville

Popular Native Perennials Suitable for Tree Planters – Full Sun						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Asclepias tuberosa	Butterfly milkweed	Plugs – 1 gal.	1 plant/18" o.c.	Dry-moist	Orange	2'
Aster novae-angliae	New England aster	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Blue	2-5'
Coreopsis lanceolata	Lance-leaf coreopsis	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Yellow	6-8'
Eupatorium purpureum	Sweet Joe-Pye Weed (Dwarf)	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Purple	3-6'
Iris virginica	Flag Iris	Plugs – 1 gal.	1 plant/18" o.c.	Moist-Wet	Blue	2'
Liatris spicata	Dense blazingstar	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Purple	1.5'
Penstemon digitalis	Smooth white beardtongue	Plugs – 1 gal	1 plant/24" o.c.	Wet	White	2-3'
Salvia lyrata	Lyre-leaf sage	Plugs – 1 gal	1 plant/18" o.c.	Moist	Purple	1-2'

Popular Native Perennials Suitable for Tree Planters – Shade						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Aquilegia canadensis	Wild columbine	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Pink	1-2.5'
Aster novae-angliae	New England aster	Plugs – 1 gal.	1 plant/24" o.c.	Moist-dry	Blue/ purple	3-4'
Aster oblongifolius	Aromatic Aster	Plugs – 1 gal.	1 plant/24" o.c.	Moist-dry	Blue/ purple	1.5-3'
Coreopsis lanceolata	Tickseed coreopsis	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Yellow	3'
Heuchera americana	Alumroot	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	1'

DT: Drought Tolerant
FT: Flood Tolerant

Popular Native Grasses and Sedges Suitable for Tree Planters						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Carex muskingumensis	Palm Sedge	1 gal.	1 plant/24" o.c.	Moist	Green	3'
Chasmanthium latifolium	Upland Sea Oats	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Green	4'
Equisetum hyemale	Horsetail	Plugs – 1 gal.	1 plant/18" o.c.	Wet	Green	3'
Juncus effesus	Soft Rush	Plugs – 1 gal.	1 plant/24" o.c.	Wet-dry	Green	4-6'
Muhlenbergia capallaris	Muhly Grass	1 gal.	1 plant/24" o.c.	Moist	Pink	3'
Panicum virgatum	Switchgrass	1-3 gal.	1 plant/48" o.c.	Moist - dry	Yellow	5-7'
Schizachyrium scoparium	Little Blue Stem	1 gal.	1 plant/24" o.c.	Moist-dry	Yellow	3'
Sporobolus heterolepsis	Prairie Dropseed	1 gal.	1 plant/24" o.c.	Moist-dry	Green	2-3'

Popular Native Trees Suitable for Tree Planters							
Latin Name	**Common Name**	**DT-FT**	**Light**	**Moisture**	**Notes**	**Flower Color**	**Height**
Acer rubrum	Red Maple	DT-FT	Sun-shade	Dry-wet	Fall color		50-70'
Betula nigra	River Birch	FT	Sun-pt shade	Moist-wet	Exfoliating bark		40-70'
Carpinus caroliniana	Ironwood		Sun-pt shade	Moist		White	40-60'
Carya aquatica	Water Hickory	FT-DT	Sun	Moist	Fall color		35-50'
Cercus Canadensis	Redbud	DT	Sun-shade	Moist	Pea-like flowers, seed pods	Purple	20-30'
Liquidambar styraciflua	Sweetgum (fruitless)	DT-FT	Sun-pt shade	Dry-moist			60-100'
Nyssa sylvatica	Black Gum		Sun-Shade	Moist	Fall color		35-50'
Platanus occidentalis	Sycamore	FT	Sun-pt shade	Moist	White mottled bark		70-100'
Quercus nuttalli	Nuttall Oak	DT	Sun	Dry-moist	Acorns		40-60'
Quercus lyrata	Overcup Oak	FT	Sun	Moist	Acorns		40-60'
Quercus shumardii	Shumard Oak	DT	Sun	Moist	Acorns		40-60'
Ulmus americana	American Elm	DT-FT	Sun-pt shade	Moist			

Popular Native Shrubs Suitable for Tree Planters							
Latin Name	**Common Name**	**DT-FT**	**Light**	**Moisture**	**Notes**	**Flower Color**	**Height**
Clethra alnifolia	Sweet Pepper Bush (Dwarf)		Sun-pt shade	Dry-moist	Hummingbirds	White	5-8'
Hydrangea quercifolia	Oakleaf Hydrangea (Dwarf)	DT	Pt shade – shade	Moist		White	3-6'
Hypericum frondosum	Golden St. John's Wort	DT	Sun-pt shade	Dry-moist	Semi-evergreen	Yellow	2-3'
Ilex glabra	Inkberry (Dwarf)	DT	Sun-pt shade	Moist-wet	Evergreen		4-8'

DT: Drought Tolerant
FT: Flood Tolerant

APPENDIX 2-E
AS-BUILT REQUIREMENTS

A printer friendly version of this table can be found on the MWS Development Services website or by request.

Urban Bioretention Number:

	Design	As-Built
Treatment Volume (Tv), CF		
Surface Area, SF		
Top of Bank Elevation		
Emergency Spillway Elevation*		
Overflow (TOC) Elevation*		
(A) GIP Surface Elevation		
(B) Top of Stone Elevation		
Underdrain Invert*		
Outlet Elevation*		
(C) Subgrade Elevation		
* N/A if not required		
ALL Elevation shall be NAVD88		

Permeable Pavement

Description: Permeable pavements allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated. Porous paving systems have several design variants that include: Permeable Interlocking Concrete Pavers (PICP), pervious concrete, and reinforced turf or gravel systems. All have a similar structure, consisting of a surface pavement layer, an underlying stone aggregate reservoir layer, and a filter layer or fabric installed on the bottom.

Advantages/Benefits:

- Runoff volume reduction
- Can increase aesthetic value
- Provides water quality treatment
- Can provide groundwater recharge

Disadvantages/Limitations:

- Cost
- Maintenance
- Limited to low traffic areas with limited structural loading
- Potential issues with handicap access
- Infiltration can be limited by underlying soil property
- Not effective on steep slopes

Selection Criteria:

40% – 80% Runoff Reduction Credit

Land Use Considerations:

- [X] **Residential**
- [X] **Commercial**
- [X] **Industrial**

Maintenance:

- Turf pavers can require mowing, fertilization, and irrigation. Plowing is possible, but requires use of skids
- Sand and salt should not be applied
- Adjacent areas should be fully stabilized with vegetation to prevent sediment-laden runoff from clogging the surface
- A vacuum-type sweeper or high-pressure hosing (for porous concrete) should be used for cleaning

[H] **Maintenance Burden**
L = Low M = Moderate H = High

SECTION 1: DESCRIPTION

Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and infiltrated. Permeable pavements consist of a surface pavement layer, an underlying stone aggregate reservoir layer and a filter layer or fabric installed on the bottom.

The thickness of the reservoir layer is determined by both a structural and hydrologic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. If infiltration rates in the native soils permit, permeable pavement shall be designed without an underdrain, to enable full infiltration of runoff. In low-infiltration soils, some of the filtered runoff is collected in an underdrain and returned to the storm drain system. A combination of these methods can be used to infiltrate a portion of the filtered runoff.

Permeable pavement is typically designed to treat stormwater that falls on the actual pavement surface area, but it may also be used to accept run-on from small adjacent impervious areas, such as impermeable driving lanes or rooftops. However, careful sediment control is needed for any run-on areas to avoid clogging of the down-gradient permeable pavement. Permeable pavement has been used at commercial, institutional, and residential sites in spaces that are traditionally impervious. Permeable pavement promotes a high degree of runoff volume reduction and nutrient removal, and it can also reduce the effective impervious cover of a development site.

SECTION 2: PERFORMANCE

The overall runoff reduction of permeable pavement is shown in **Table 3.1**.

Table 3.1. Runoff Volume Reduction Provided by Permeable Pavement

Stormwater Function	Level 1 Design	Level 2 Design
Runoff Volume Reduction (RR)	40%	80%
Treatment Volume (Tv) Multiplier*	1.0	1.25

*Incorporated into LID Site Design Tool spreadsheet calculations
Sources: CSN (2008) and CWP (2007)

SECTION 3: TYPICAL DETAILS

See **Appendix 3-B** and **3-C** for required standard notes and typical details for use in construction plans.

SECTION 4: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Since permeable pavement has a very high runoff reduction capability, it should always be considered as an alternative to conventional pavement. 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. Permeable pavement is subject to the same considerations as most infiltration practices, as described below.

Types of Surface Pavement. Permeable Interlocking Concrete Pavers (PICP), pervious concrete, and reinforced turf or gravel systems are permitted.

Infiltration/Soils. Infiltration is a key component of Low Impact Development design. Infiltration testing may be required for permeable pavement areas (see Section 5.1). Soil conditions do not constrain the use of permeable pavement but can affect the design requirements. Hydrologic Soil Groups (HSG) should be determined from NRCS soil data. For more information on soil types go to: http://websoilsurvey.nrcs.usda.gov/app/. Alternative HSG classifications will be considered when supporting reports from a licensed soil scientist or geotechnical engineer are provided.

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 prices are high.

Accessibility. Permeable pavement facilities must be accessible to various types of equipment for periodic maintenance.

Contributing Drainage Area. Field experience has shown that an upgradient drainage area (even if it is impervious) can contribute particulates to the permeable pavement and lead to clogging (Hirschman, et al., 2009). Therefore, careful sediment source control and/or a pre-treatment strip or sump (e.g., stone or gravel) should be used to control sediment run-on to the permeable pavement section. For Level 1 permeable pavement, the external drainage area contributing runoff to permeable pavement should be less than or equal to the area of the permeable pavement itself (i.e. 1:1 ratio) and it should be as close to 100% impervious as possible. No external drainage area will be allowed to run-on to Level 2 permeable pavement. Nominal areas of run-on (e.g. landscapes islands and sidewalks) can be permitted with MWS staff approval. See Section 5.2.3 for an Alternative Design Method to increase contributing drainage.

Pavement Slope. Steep slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. The surface slope should be less than 10% to encourage infiltration but is not recommended to be more than 1%. The subgrade slope of a permeable pavement installation should be as flat as possible (i.e., 0-1% longitudinal slope) in order to establish level reservoir storage areas. This promotes even distribution and infiltration of the required treatment volume storage. Designers shall use a terraced subgrade design for permeable pavement in sloped areas, especially when the surface slope is greater than 1%. Lateral slopes should be 0%.

Subsurface Constraints. Permeable pavement subgrade shall always be separated from the water table and bedrock. A separation distance of 2 feet is required between the bottom of the excavated permeable pavement area and the seasonally high ground water table and/or bedrock.

Utilities. Public underground utilities and associated easements shall not be located within the permeable pavement footprint. Local utility design guidance shall be consulted in order to determine clearances required between stormwater infrastructure and other dry and wet utility lines. Private utilities should not be located within the permeable pavement area when possible.

Hotspot Land Uses. Runoff from hotspot land uses should not be treated with infiltrating permeable pavement without appropriate pretreatment and MWS staff approval. For additional information on stormwater hotspots, please consult **Section 6.3**.

Floodplains. Permeable pavement shall be constructed outside the limits of the 100-year floodplain. Flood waters from the 100-year event or smaller shall be prohibited from entering the overflow system.

Setbacks. It is not recommended to place permeable pavement areas immediately adjacent to structures. To avoid the risk of seepage, a licensed professional engineer should be consulted to determine the appropriate setbacks necessary to prevent permeable pavement infiltration from compromising structural foundations or pavement. At a minimum, permeable pavement areas should be located a horizontal distance of 100 feet from any water supply well and 50 feet from septic systems.

Applications. Permeable pavement can be used as an alternative to most types of conventional pavement at residential, commercial and institutional developments; however, it is not currently approved for use in the Right of Way (ROW).

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. Designers should determine structural design requirements by consulting transportation design guidance sources and the manufacturer's specific recommendations.

The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (CBR) (less than 4%), they may need to be compacted to at least 95% of the Standard Proctor Density, which generally rules out their use for infiltration.

SECTION 5: DESIGN CRITERIA

5.1 Soil Infiltration Rate Testing

Infiltration testing is optional for permeable pavement due to the possibility of having to compact the subgrade to support vehicle loading. If during the design phase it is determined that subgrade compaction will be required, the designer should consider using underdrains. Otherwise, test pit(s), compacted to the necessary density, must be utilized on the site to determine infiltration.

To perform infiltration testing one must measure the infiltration rate of subsoils at the subgrade elevation of the permeable pavement area. If the infiltration rate exceeds 0.5 inch per hour, an underdrain should not be utilized. If the infiltration rate of subsoils is greater than 0.1 inch per hour and less than or equal to 0.5 inch per hour, underdrains will be required. On-site soil infiltration rate testing procedures are outlined in **Appendix 3-A**. The number of soil tests varies based on the size of the permeable pavement area:

- < 1,000 ft^2 = 2 tests
- 1,000 – 10,000 ft^2 = 4 tests
- >10,000 ft^2 = 4 tests + 1 test for every additional 5,000 ft^2

If an underdrain with a gravel sump is used for Level 2, the bottom of the sump must be at least two feet above bedrock and the seasonally high groundwater table.

For sites with large amounts of cut or fill it may not be practical to perform infiltration testing prior to grading the site. In these cases, a mass grading permit will be required.

5.2 Sizing of Permeable Pavement Practices

5.2.1 Stormwater Quality

Sizing of the surface area (SA) for permeable pavement practices is based on the computed Treatment Volume (T_v) of the contributing drainage area and the storage provided in the facility. The required surface area (in square feet) is computed as the Treatment Volume (in cubic feet) divided by the equivalent storage depth (in feet). The equivalent storage depth is computed as the depth of gravel (in feet) multiplied by the accepted porosity (see **Table 3.2**). See Section 5.5 for material specifications. Based on volume calculations, the minimum 8" reservoir layer is sufficient to contain the required Treatment Volume for the typical permeable pavement contributing drainage area (see Section 4).

Table 3.2 Permeable Pavement Typical Section for Water Quality Calculations

Infiltration (i)	N/A	i > 0.5"/hr	i ≤0.5"hr	Porosity Value (n)
	Level 1 (inches)	Level 2 (inches)	Level 2 (inches)	
Permeable pavement*	Varies based on type and manufacturer's specification			N/A
Bedding	Varies based on type and manufacturer's specification			N/A
Reservoir (minimum)	8	8	8	0.40
Sump*	0	0	12	0.40
Sand Choker**	2-4	2-4	2-4	N/A

* Cannot be used in De and surface area calculations.
**Filter fabric can be used as an alternative (see Section 5.5)

5.2.2 Stormwater Quantity

If designed with sufficient volume and appropriate outlet structures including a high flow bypass, peak attenuation control may be provided by the permeable pavement. Hydrologic calculations utilizing the SCS method may be necessary to demonstrate pre versus post peak flow rates.

Subsurface Storage. Designers may be able to create additional subsurface storage for flow attenuation by increasing the subsurface volume without necessarily increasing the permeable pavement footprint. Additional volume can be provided by increasing the depth of the reservoir layer with additional stone or approved proprietary storage products. Subsurface storage within the sump layer will not be allowed without infiltration rates greater than 0.5 inch per hour. (see Section 5.1).

Adjusted CN. With infiltration rates greater than 0.5 inch per hour (see Section 5.1), the removal of volume by permeable pavement changes the runoff depth entering downstream flood control facilities. An approximate approach to accounting for the removal of volume is to calculate an "effective SCS curve number" (CN_{adj}), which is less than the actual curve number (CN). CN_{adj} can then be used in hydrologic calculations and in routing. This method is detailed in Volume 5 Section 3.2.5.

5.2.3 Alternative Design Method

Studies show that maintained permeable pavements produce very little surface runoff. Consequently, practices in well drained soils with adequate storage and no underdrain yield very high runoff reduction results. Therefore, increasing the contributing drainage area to a maximum 3:1 ratio to the permeable pavement surface area can be considered. For example, a permeable pavement area of 100 SF could receive up to 300 SF of additional contributing drainage area outside of the permeable pavement footprint.

This alternative design method can be used for level 1 and level 2 facilities that are utilizing reinforced turf systems, reinforced gravel systems, or concrete pavers. To determine if the alternative design method can be utilized, infiltration rates must meet or exceed 0.5 inch per hour (Section 5.1).

Use the following equation to calculate the required reservoir depth :

Equation 3.1. Required Depth of Reservoir Layer

$$D_{r-req} = \frac{T_{v-req}}{SA\ * n}$$

Where:

$D_{r\text{-}req}$	=	The required depth of the reservoir layer (ft.); 8-inch minimum
$T_{v\text{-}req}$	=	The required treatment volume (cu. ft.)
SA	=	The surface area of the permeable pavement (sq. ft.)
n	=	The porosity for the reservoir layer (0.4)

The maximum allowable depth of the reservoir layer is constrained by the maximum allowable drain time, which is calculated using **Equation 3.2**.

Equation 3.2. Maximum Depth of Reservoir Layer

$$D_{r-max} = \frac{\left({}^{i}/_{2} \times t_d\right)}{n}$$

Where:

$D_{r\text{-}max}$	=	The maximum depth of the reservoir layer (ft.)
i	=	The field-verified infiltration rate for native soils (ft./day)
t_d	=	The maximum allowable time to drain the reservoir layer, typically 48 hours
n	=	The porosity for the reservoir layer (0.4)

The required depth of the reservoir layer ($D_{r\text{-}req}$) must not exceed the maximum depth of reservoir layer ($D_{r\text{-}max}$). If $D_{r\text{-}req}$ exceeds $D_{r\text{-}max}$, then the run-on ratio must be reduced.

5.3 Pretreatment

Pretreatment for most permeable pavement applications is not necessary, since the surface acts as pretreatment to the reservoir layer below. Additional pretreatment is required if the pavement receives run-on from an adjacent pervious or impervious area. For example, a gravel filter strip can be placed along the edge of the permeable pavement section to trap coarse sediment particles before reaching the permeable pavement surface.

5.4 Conveyance and Overflow

Permeable pavement designs should include methods to convey larger storms (e.g., 2-yr, 10-yr) to the storm drain system. This can be accomplished by placing storm drain inlets at the lowest elevation of the permeable pavement surface.

5.5 Permeable Pavement Material Specifications

Table 3.3 outlines the standard material specifications used to construct permeable pavement areas. Designers should consult manufacturer's technical specifications for specific criteria and guidance.

Table 3.3. Material Specifications for Underneath the Pavement Surface

Material	Specification	Notes
Permeable Pavement System	Permeable Interlocking Concrete Pavers Pervious Concrete Reinforced Turf Systems Reinforced Gravel Systems	ASTM C936 ASTM C1688/C1688M & ACI 522 ASTM D638 ASTM D638
Bedding Layer	#8 or #89 clean washed stone	Meet TDOT Construction Specifications.
Reservoir Layer	#57 or #2 clean washed stone	Meet TDOT Construction Specifications.
Underdrain	4- or 6-inch dual wall HDPE or SDR 35 PVC pipe with 3/8-inch perforations at 6 inches on center	AASHTO M 252 Place perforated pipe at base of reservoir layer at the lower end of the paver cell.
Cleanout	6-inch SDR 35 PVC pipe with vented cap	Use traffic rated casting where required. Provide cleanouts at the upper end of the underdrain.
Observation Well	6-inch SDR 35 PVC pipe with vented cap and anchor plate	Use traffic rated casting where required. Number of wells equals the number of test pits required for infiltration testing (see Appendix 3-A)
Sand Choker/Geotextile	2- to 4-inch layer of coarse sand Filter fabric (125 gpm/sq.ft.)	Meet TDOT Construction Specifications AASHTO M288-06, ASTM D4491 & D4751
Impermeable Liner (if needed)	Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd.^{2} non-woven geotextile.	

SECTION 6: SPECIAL CASE DESIGN ADAPTATIONS

6.1 Shallow Bedrock and Groundwater Connectivity

Many parts of Nashville have shallow bedrock, which can constrain the application of infiltrative permeable pavement areas. In such settings, other GIPs may be more applicable.

For more information on bedrock depths download the GIS data set from: http://water.usgs.gov/GIS/metadata/usgswrd/XML/regolith.xml.

6.2 Karst

Karst regions are found in much of Middle Tennessee, which complicates both land development and stormwater design. Infiltrative permeable pavement designs shall not be used in any area with a high risk of sinkhole formation. On the other hand, non-infiltrative designs that meet separation distance requirements (2 feet) and possess an impermeable bottom liner and an underdrain can be considered.

6.3 Hotspots

Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk for spills, leaks or illicit discharges. Infiltrative permeable pavement designs shall not be used in any area with a hotspot designation without appropriate pretreatment, impermeable barriers, and MWS staff approval.

SECTION 7: CONSTRUCTION

7.1 Construction

Construction Stage Erosion and Sediment Controls. Permeable pavement areas should be fully protected from sediment laden runoff and vehicular tracking during construction. Ideally, permeable pavement areas should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment.

Sediment traps or basins may be located within permeable pavement excavation limits during construction. However, these must be accompanied by notes and graphic details on the erosion prevention and sediment control (EPSC) plan specifying that the maximum excavation depth at the construction stage must be at least 1 foot above the post-construction subgrade elevation. The plan must also show the proper procedures for converting the temporary sediment control practice to a permeable pavement facility, including dewatering, cleanout and stabilization.

Excavation. The proposed site should be checked for existing utilities prior to any excavation. It is very important to minimize compaction of both the base of the permeable pavement area and the required backfill. When possible, excavators should work from the sides of the permeable pavement area to remove original soil. If the permeable pavement area is excavated using a loader, the contractor must use wide track or marsh track equipment, or light equipment with turf type tires. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high-pressure tires will cause excessive compaction resulting in reduced infiltration rates and is not acceptable. Compaction will significantly contribute to design failure of infiltrative permeable pavement areas.

7.2 Permeable Pavement Installation

Construction should take place during appropriate weather conditions. The following is a typical construction sequence to properly install permeable pavement. These steps may be modified to reflect different permeable pavement applications or expected site conditions:

Step 1. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area 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 permeable pavement 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 2. Ensure that the entire contributing drainage area has been stabilized prior to permeable pavement construction. Otherwise, use EPSC measures as outlined in Section 7.1.

Step 3. Excavation to the base of the permeable pavement should follow the guidelines found in Section 7.1. Contractors should use a cell construction approach in larger permeable pavement areas.

Step 4. The native soils along the bottom and sides of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the filter layer or filter fabric. 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. Install all layers and components of the permeable pavement per plans.

Step 6. Conduct the final construction inspection (see **Section 8**). Then log the GPS coordinates for each permeable pavement facility and submit them to MWS.

SECTION 8: AS-BUILT REQUIREMENTS

After the permeable pavement area has been constructed, the owner/developer must have an as-built certification of the permeable pavement area conducted by a registered Professional Engineer. The as-built certification verifies that the GIP was installed per the approved plan. The following items shall be provided in addition to the as-built requirements found in SWMM Volume 1.

1. The Engineer shall include a copy of the GIP summary table found in **Appendix 3-D**.
2. Topographic survey of the subgrade when benching or subsurface terracing is used.
3. Supporting documents such as invoices and photographs should be included in the submittal package.

SECTION 9: MAINTENANCE

9.1 Maintenance Document

The requirements for the Maintenance Document are in Appendix C of Volume 1 of the Manual. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities. The LTMP for permeable pavement should also note which conventional parking lot maintenance tasks must be *avoided* (e.g., sanding, re-sealing, re-surfacing, power-washing). Signs should be posted on larger parking lots to indicate their stormwater function and special maintenance requirements.

9.2 Maintenance Tasks

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. Most installations work reasonably well year after year with little or no maintenance, whereas some have problems right from the start.

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. Vacuum settings for large-scale interlocking paver applications should be calibrated so they *do not* pick up the stones between pavement blocks.

9.3 Maintenance Inspections

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each permeable pavement site, particularly at large-scale applications.

Maintenance of permeable pavement is driven by annual inspections that evaluate the condition and performance of the practice. The following are suggested annual maintenance inspection points for permeable pavements:

- The drawdown rate should be measured at the observation well for three (3) days following a storm event in excess of 0.5 inch in depth. If standing water is still observed in the well after three days, this is a clear sign that clogging is a problem.
- Inspect the surface of the permeable pavement for evidence of sediment deposition, organic debris, staining or ponding that may indicate surface clogging. If any signs of clogging are noted, schedule a vacuum sweeper (no brooms or water spray) to remove deposited material. Then, test sections by pouring water from a five-gallon bucket to ensure they work.
- Inspect the structural integrity of the pavement surface, looking for signs of surface deterioration, such as slumping, cracking, spalling or broken pavers. Replace or repair affected areas, as necessary.
- Check inlets, pretreatment cells and any flow diversion structures for sediment buildup and structural damage. Note if any sediment needs to be removed.
- Inspect the condition of the observation well and make sure it is still capped.
- Generally, inspect any contributing drainage area for any controllable sources of sediment or erosion.

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

The following is a list of some community and environmental concerns that may arise when infiltration practices are proposed:

Compliance with the Americans with Disabilities Act (ADA). Porous concrete is generally considered to be ADA compliant. Interlocking concrete pavers are considered to be ADA compliant, if designers ensure that surface openings between pavers do not exceed 0.5 inch. However, some forms of interlocking pavers may not be suitable for handicapped parking spaces. Interlocking concrete pavers interspersed with other hardscape features (e.g., concrete walkways) *can* be used in creative designs to address ADA issues.

Vehicle Safety. Permeable pavement is generally considered to be a safer surface than conventional pavement, according to research reported by Smith (2006) and Jackson (2007). Permeable pavement has less risk of hydroplaning, more rapid ice melt and better traction than conventional pavement.

Air and Runoff Temperature. Permeable pavement appears to have some value in reducing summer runoff temperatures, which can be important in watersheds with sensitive cold-water fish populations. The temperature reduction effect is greatest when runoff is infiltrated into the sub-base, but some cooling may also occur in the reservoir layer, when underdrains are used. ICPI (2008) notes that the use of certain reflective colors for interlocking concrete pavers can also help moderate surface parking lot temperatures.

Groundwater Injection Permits. Groundwater injection permits are required if the infiltration practice is deeper than the longest surface area dimension of the practice. Designers should investigate whether or not a proposed infiltration practice is subject to Tennessee groundwater injection well permit requirements.

SECTION 11: REFERENCES

AG-588-14. North Carolina State University. Raleigh, NC. Available online at: http://www.bae.ncsu.edu/stormwater/PublicationFiles/ Perm Pave2008.pdf.

American Society for Testing and Materials (ASTM). 2003. "Standard Classification for Sizes of Aggregate for Road and Bridge Construction." *ASTM D448-03a.* West Conshohocken, PA.

Chesapeake Stormwater Network (CSN). 2009. Technical Bulletin No. 1. *Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay watershed. Version 2.0*. Baltimore, MD. Available online at: http://www.chesapeakestormwater.net/all-things-stormwater/stormwater-guidance-for-karst-terrain-in-the-chesapeake-bay.html

CWP. 2007. *National Pollutant Removal Performance Database, Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Hathaway, J. and W. Hunt. 2007. *Stormwater BMP Costs*. Report to NC DEHNR. Department of Biological and Agricultural Engineering. North Carolina State University. Raleigh, NC.

Hirschman, D., L. Woodworth and S. Drescher. 2009. *Technical Report: Stormwater BMPs in Virginia's James River Basin: An Assessment of Field Conditions & Programs*. Center for Watershed Protection. Ellicott City, MD.

Hunt, W. and K. Collins. 2008. "Permeable Pavement: Research Update and Design Implications." *North Carolina Cooperative Extension Service Bulletin.* Urban Waterways Series.

Interlocking Concrete Pavement Institute (ICPI). 2008. *Permeable Interlocking Concrete Pavement: A Comparison Guide to Porous Asphalt and Pervious Concrete.*

Jackson, N. 2007. *Design, Construction and Maintenance Guide for Porous Asphalt Pavements*. National Asphalt Pavement Association. Information Series 131. Lanham, MD. Available online at: www.hotmix.com

Northern Virginia Regional Commission (NVRC). 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook*. Fairfax, Virginia

Sustainable Infrastructure Alternative Paving Materials Subcommittee Report. Portland, Oregon. Available online at: http://www.portlandonline.com/bes/index.cfm?c=34602&

Schueler, T., C. Swann, T. Wright and S. Sprinkle. 2004. *Pollution source control practices*. Manual No. 8 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

Schueler et al 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Smith, D. 2006. *Permeable Interlocking Concrete Pavement-selection design, construction and maintenance. Third Edition*. Interlocking Concrete Pavement Institute. Herndon, VA.

Tennessee Department of Environment and Conservation (TDEC), 2014. *Tennessee Permanent Stormwater*

Management and Design Guidance Manual. Nashville, TN.

TDOT. 2010. *Roadway Design Guidelines.* Tennessee Department of Transportation, Nashville, TN. http://www.tdot.state.tn.us/Chief_Engineer/assistant_engineer_design/design/DesGuide.htm.

U.S EPA. 2008. June 13 2008 Memo. L. Boornaizian and S. Heare. "Clarification on which stormwater infiltration practices/technologies have the potential to be regulated as "Class V" wells by the Underground Injection Control Program." Water Permits Division and Drinking Water Protection Division. Washington, D.C.

Virginia Department of Conservation and Recreation (VADCR). 2011. Stormwater Design Specification No. 7: Permeable Pavement, version 1.8, March 1, 2011.

Virginia Department of Environmental Quality (VADEQ). 2013. Stormwater Design Specification No. 7: Permeable Pavement, version 2.0.

Water Environment Research Federation (WERF). 2005. *Performance and Whole-life Costs of Best Management Practices and Sustainable Urban Drainage Systems*. Alexandria, VA.

APPENDIX 3-A

INFILTRATION SOIL TESTING PROCEDURES

I. Test Pit/Boring Procedures

1. The number of required test pits or standard soil borings is based on proposed infiltration area:
   - < 1,000 ft^2 = 2 tests
   - 1,000 – 10,000 ft^2 = 4 tests
   - >10,000 ft^2 = 4 tests + 1 test for every additional 5,000 ft^2
2. The location of each test pit or standard soil boring should correspond to the location of the proposed infiltration area.
3. Excavate each test pit or penetrate each standard soil boring to a depth at least 2 feet below the bottom of the proposed infiltration area.
4. If the groundwater table is located within 2 feet of the bottom of the proposed facility, determine the depth to the groundwater table immediately upon excavation and again 24 hours after excavation is completed.
5. Determine the USDA or Unified Soil Classification system textures at the bottom of the proposed infiltration area and at a depth that is 2 feet below the bottom. All soil horizons should be classified and described.
6. If bedrock is located within 2 feet of the bottom of the proposed infiltration area, determine the depth to the bedrock layer.
7. Test pit/soil boring stakes should be left in the field to identify where soil investigations were performed.

II. Infiltration Testing Procedures

1. The number of required infiltration tests is based on proposed infiltration area:
   - < 1,000 ft^2 = 2 tests
   - 1,000 – 10,000 ft^2 = 4 tests
   - >10,000 ft^2 = 4 tests + 1 test for every additional 5,000 ft^2
2. The location of each infiltration test should correspond to the location of the proposed infiltration area.
3. Install a test casing (e.g., a rigid, 4 to 6 inch diameter pipe) to a depth 2 feet below the bottom of the proposed infiltration area.
4. Remove all loose material from the sides of the test casing and any smeared soil material from the bottom of the test casing to provide a natural soil interface into which water may percolate. If desired, a 2-inch layer of coarse sand or fine gravel may be placed at the bottom of the test casing to prevent clogging and scouring of the underlying soils. Fill the test casing with clean water to a depth of 2 feet, and allow the underlying soils to presoak for 24 hours.
5. After 24 hours, refill the test casing with another 2 feet of clean water and measure the drop in water level within the test casing after one hour. Repeat the procedure three (3) additional times by filling the test casing with clean water and measuring the drop in water level after one hour. A total of four (4) observations must be completed. The infiltration rate of the underlying soils may be reported either as the average of all four observations or the value of the last observation. The infiltration rate should be reported in terms of inches per hour.
6. Infiltration testing may be performed within an open test pit or a standard soil boring.
7. After infiltration testing is completed, the test casing should be removed, and the test pit or soil boring should be backfilled and restored.

APPENDIX 3-B
STANDARD NOTES

Required Permeable Pavement Notes:

- Vehicular traffic shall be prohibited on the pervious pavement until the site is stable to prevent sediment from being deposited by vehicles.
- Contractor, Engineer, or Owners Representative shall notify MWS NPDES at least 48 hours prior to the installation of the pervious layer to observe the sub-base material.

APPENDIX 3-C
STANDARD DETAILS

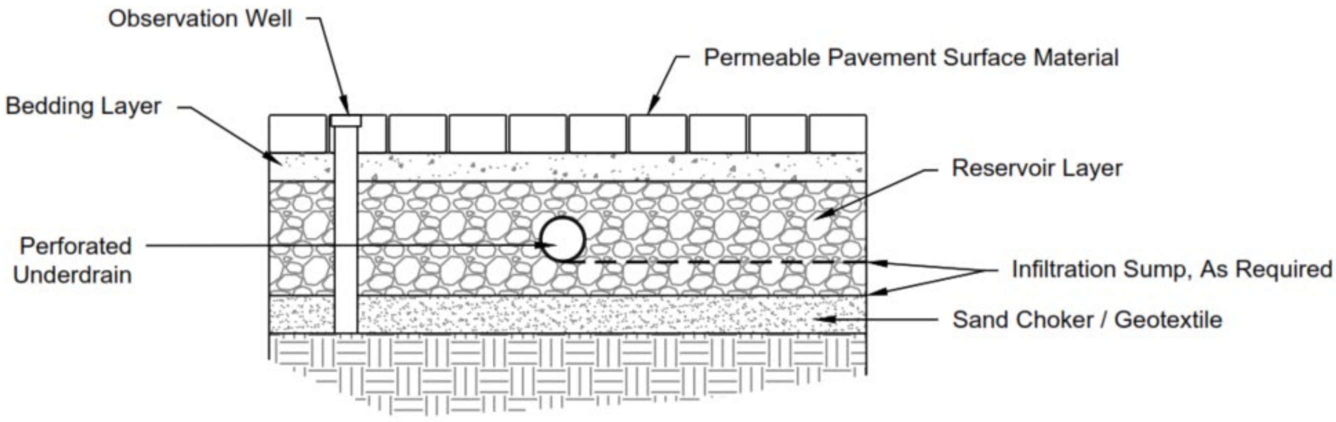


Figure 3.1. Permeable Pavers with Underdrain

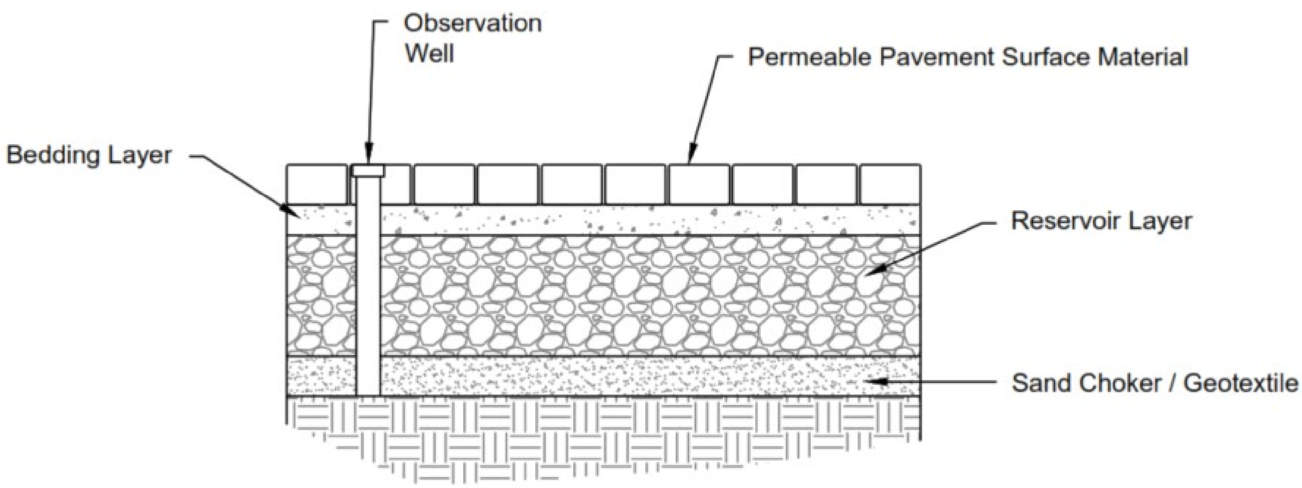


Figure 3.2. Permeable Pavers without Underdrain

APPENDIX 3-D
AS-BUILT REQUIREMENTS

A printer friendly version of this table can be found on the MWS Development Services website or by request.

Permeable Pavement Number:

	Design	As-built
Treatment Volume (Tv), CF		
Surface Area, SF		
Overflow (TOC) Elevation*		
Reservoir Depth		
Underdrain Invert Depth*		
Outlet Elevation*		
Sump Depth		
* N/A if not required		
ALL Elevation shall be NAVD88		

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Infiltration Trenches

Description: Excavated trench filled with stone aggregate used to capture and allow infiltration of stormwater runoff into the surrounding soils from the bottom and sides of the trench. Runoff from each rain event is captured and treated primarily through settling and filtration.

Advantages/Benefits:

- Provides for groundwater recharge
- Good for small sites with porous soils
- Cost effective
- Groundwater recharge (if soils are sufficiently permeable)

Disadvantages/Limitations:

- Potential for groundwater contamination
- High clogging potential; should not be used on sites with fine-particle soils (clays or silts) in drainage area
- Cannot be used in karst soils
- Geotechnical testing required

Selection Criteria:

50% – 90% Runoff Reduction Credit

Land Use Considerations:

- [X] **Residential**
- [X] **Commercial**
- [X] **Industrial**

Maintenance:

- Inspect for clogging
- Remove sediment from forebay
- Replace pea gravel layer as needed
- Maintain side slopes/remove invasive vegetation

[H] **Maintenance Burden**
L = Low M = Moderate H = High

SECTION 1: DESCRIPTION

Using the natural filtering properties of soil, infiltration trenches can remove a wide variety of pollutants from stormwater through sorption, precipitation, filtering, and bacterial and chemical degradation. Infiltration trenches are excavations typically filled with stone to create an underground reservoir for stormwater runoff. By diverting runoff into the soil, an infiltration trench not only treats the water quality volume, but also helps to preserve the natural water balance on a site and can recharge groundwater and preserve base flow. Due to this fact, infiltration systems are limited to areas with highly porous soils where the water table and/or bedrock are located well below the bottom of the trench.

In addition, infiltration trenches must be carefully located to avoid the potential of groundwater contamination. Infiltration trenches are not intended to trap sediment and must always be designed with appropriate pretreatment measures to prevent clogging and failure. Due to their high potential for failure, these facilities must only be considered for sites where upstream sediment control can be ensured.

SECTION 2: PERFORMANCE

When used appropriately, infiltration has a very high runoff volume reduction capability, as shown in **Table 4.1.**

Table 4.1. Summary of Runoff Reduction Provided by Infiltration[1]		
Stormwater Function	**Level 1 Design**	**Level 2 Design**
Runoff Volume Reduction (RR)	50%	90%
Treatment Volume (Tv) Multiplier*	1.0	1.25
Soil Infiltration Rate	> 0.5 in/hr & < 1 in/hr	$\geq$ 1 in/hr

*Incorporated into LID Site Design Tool calculations
[1] CSN (2008) and CWP (2007)

SECTION 3: TYPICAL DETAILS

See Appendix 4-B and 4-C for required standard notes and applicable details for use in construction plans.

SECTION 4: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Infiltration trenches are generally suited for areas where the subsoil is sufficiently permeable to provide a reasonable infiltration rate. Infiltration trenches can either be used to capture sheet flow from a drainage area or function as an off-line device. Key considerations with infiltration trenches include the following:

Infiltration/Soils. Infiltration is a key component of Low Impact Development (LID) design. Infiltration testing shall be required for all infiltration trenches (see Section 5.1). Soil conditions can constrain the use of infiltration trenches. Hydrologic Soil Groups (HSG) should be determined from NRCS soil data. For more information on soil types go to: http://websoilsurvey.nrcs.usda.gov/app/. Alternative HSG classifications will be considered when supporting reports from a licensed soil scientist or geotechnical engineer are provided.

Available Space. Planners and designers can assess the feasibility of using infiltration trenches based on a simple relationship between the contributing drainage area (CDA) and the corresponding required surface area. The infiltration trench surface area will depend on the imperviousness of the CDA, the subsoil infiltration rate, and the desired infiltration trench design level. Due to the relatively narrow shape, infiltration trenches can be adapted to many different types of sites and can be utilized in retrofit situations. Unlike some other structural stormwater controls, they can easily fit into the margin, perimeter, or other unused areas of developed sites.

Accessibility. Infiltration trenches require periodic maintenance and must be accessible to various types of equipment. A path of travel for equipment no less than twelve feet in width with a maximum slope of 3:1 must be provided for the infiltration trench. The path of travel shall be along no less than 50% of the perimeter of the infiltration trench and must be accessible by common equipment and vehicles.

Elevation Considerations. Infiltration trenches shall be located on slopes less than 15% and a minimum of 200 feet away from downstream slopes greater than 20%. Terracing or other inlet controls upstream may be used to slow runoff velocities entering the facility. Infiltration trenches cannot be used in fill soils.

Subsurface Constraints. Vertical constraints such as retaining walls, structures, or other impermeable barriers are prohibited around the infiltration trench perimeter. Infiltration trench subgrade shall always be separated from the water table and bedrock. Groundwater intersecting the filter bed can lead to possible groundwater contamination or failure of the infiltration trench. A separation distance of 2 feet is required between the bottom of the excavated infiltration trench and the seasonally high ground water table and/or bedrock.

Utilities. Public underground utilities and associated easements shall not be located within the infiltration trench footprint. Local utility design guidance shall be consulted in order to determine clearances required between stormwater infrastructure and other dry and wet utility lines. Private utilities should not be located within the infiltration trench when possible.

Contributing Drainage Area. Infiltration trenches are applicable primarily for impervious areas where there are not high levels of fine particulates (clay/silt soils) in the runoff and should only be considered for sites where the sediment load is relatively low. Infiltration trenches are best applied when the grade of contributing slopes is less than 15%. Typical drainage area size can range from 0.1 to 2.0 acres of impervious cover. Contributing drainage areas to infiltration trenches shall be clearly conveyed in the construction plans.

Hotspot Land Uses. Runoff from hotspot land uses should not be treated with infiltration trenches without appropriate pretreatment and MWS staff approval. For additional information on stormwater hotspots, please consult **Section 6.3**.

Floodplains. Infiltration trenches shall be constructed outside the limits of the 100-year floodplain. Flood waters from the 100-year event or smaller shall be prohibited from entering the overflow system.

Baseflow. The planned infiltration trench shall not receive baseflow, chlorinated wash-water or other such non-stormwater flows.

Setbacks. It is not recommended to place infiltration trenches immediately adjacent to structures. To avoid the risk of seepage, a licensed professional engineer should be consulted to determine the appropriate setbacks necessary to prevent the infiltration trench from compromising structural foundations or pavement. At a minimum, infiltration trenches should be located a horizontal distance of 25 feet from building foundations, 100 feet from any water supply well, and 50 feet from septic systems.

Applications. Infiltration trenches are generally suited for medium-to-high density residential, commercial and institutional developments. It should be noted that special care must be taken to provide adequate pretreatment for infiltration trenches in space-constrained high traffic areas. Typical locations for infiltration trenches could include parking lot features and unused pervious areas on a site.

Infiltration trenches shall not be located below paved surfaces.

SECTION 5: DESIGN CRITERIA

5.1 Soil Infiltration Rate Testing

One must measure the infiltration rate of subsoils at the subgrade elevation of the infiltration trench. The infiltration rate shall exceed 0.5 inch per hour. If the infiltration rate is 0.5 inch per hour or less infiltration trenches shall not be used. On-site soil infiltration rate testing procedures are outlined in **Appendix 4-A**. The number of soil tests varies based on the length of the infiltration trench:

- ≤50 linear feet = 2 tests
- >50 linear feet = 2 tests + 1 test for every additional 50 linear feet

A separation distance of 2 feet is required between the bottom of the excavated infiltration trench and the seasonally high ground water table and/or bedrock.

For sites with large amounts of cut or fill it may not be practical to perform infiltration testing prior to grading the site. In these cases, a mass grading permit will be required.

5.2 Sizing of Infiltration Trenches

5.2.1 Stormwater Quality

Sizing of the surface area (SA) for the infiltration trench is based on the computed Treatment Volume (T_v) of the contributing drainage area and the storage provided in the facility. The required surface area (in square feet) is computed as the Treatment Volume (in cubic feet) divided by the equivalent storage depth (in feet). The equivalent storage depth is computed as the depth of gravel and surface ponding multiplied by the accepted porosity. All layer depths shall be uniform with regard to surface area. The surface should generally be flat, so the infiltration trench fills up like a bathtub. See Section 5.5 for material specifications.

Table 4.2 Infiltration Trench Typical Section for Water Quality Calculations

	Level 1 or Level 2 (inches)	Porosity Value (n)
Ponding	6	1.0
Surface Cover	3	0.40*
Choker	3	0.40
Reservoir	36-96	0.40
Trench Bottom	6	N/A
* Cannot be used in De and surface area calculations when using turf.		

The equivalent storage depth for Level 1 and 2 is therefore computed as:

Equation 4.1. Infiltration Trench Level 1 and 2 Design Storage Depth

$$\text{Equivalent Storage Depth} = D_E = n_1(D_1) + n_2(D_2) + \cdots$$

$$D_E = (3 \text{ to } 8 \text{ ft.} \times 0.4) + (0.5 \times 1.0) = 1.7 \text{ to } 3.7 \text{ ft.}$$

Therefore, the Level 1 Infiltration Trench Surface Area (SA) is computed as:

Equation 4.2. **Infiltration Trench** *Level 1 Design Surface Area*

$$SA \text{ (sq. ft.)} = [(1.00 * T_v) – \text{the volume reduced by an upstream SCM}] / D_E$$

And the Level 2 Infiltration Trench Surface Area is computed as:

Equation 4.3. **Infiltration Trench** *Level 2 Design Surface Area*

$$SA \text{ (sq. ft.)} = [(1.25 * Tv) – \text{the volume reduced by an upstream SCM}] / D_E$$

Where:

SA = Minimum surface area of Infiltration Trench filter (sq. ft.)

D_E = *Equivalent Storage Depth (ft.)*

T_v = Treatment Volume (cu. ft.) = [(1.0 in.)(R_v)(A)*3630]

5.2.2 Stormwater Quantity

It is recommended that rain events larger than the 1-inch storm bypass infiltration trenches to prevent additional maintenance burden. However, if designed with sufficient volume and appropriate outlet structures, peak attenuation control utilizing exfiltration may be provided. Hydrologic calculations utilizing the SCS method may be necessary to demonstrate pre versus post peak flow rates.

Surface Storage. Designers may be able to create surface storage by locating infiltration trenches within dry detention ponds.

Subsurface Storage. Designers may be able to create additional subsurface storage for flow attenuation by increasing the subsurface volume without necessarily increasing the infiltration trench footprint. Additional volume can be provided by increasing the depth of stone or approved proprietary storage products. Subsurface storage will not be allowed without sufficient infiltration (see Section 5.1). Maximum trench depth of 10 feet.

Adjusted CN. With infiltration rates greater than 0.5 inch per hour (see Section 5.1), the removal of volume by infiltration trenches changes the runoff depth entering downstream flood control facilities. An approximate approach to accounting for the removal of volume is to calculate an "effective SCS curve number" (CN_{adj}), which is less than the actual curve number (CN). CN_{adj} can then be used in hydrologic calculations and in routing. This method is detailed in Volume 5 Section 3.2.5.

5.3 Pretreatment/Inlets

Pretreatment facilities must always be used in conjunction with an infiltration trench to remove floatables and sediment to prevent clogging and failure. Every infiltration practice should include multiple pretreatment techniques, although the nature of pretreatment practices depends on the type of flow received. The number, volume and type of acceptable pretreatment techniques needed for the types of receiving flow are found in **Table 4.3**.

Volumetric pretreatment practices, such as forebays, are sized based on a percentage of the required treatment volume of the GIP. The percentage requirement for the pretreatment practice is exclusive of the required treatment volume for the GIP. Exclusive, in this application, is defined as being separate from the required treatment volume of the GIP. The volume provided by pretreatment practices cannot be included in the calculation for overall treatment volume provided by the GIP.

Table 4.3. Required Pretreatment Elements for Infiltration Practices

Flow Type	Pretreatment Options
Point/ Concentrated*	• **Forebay** o 15% pretreatment volume (exclusive) o enhanced check dam (TDOT EC-STR-6A); or approved equivalent o flat bottom without stone • **Proprietary structure** (MWS approval)
Sheet	Gravel diaphragm to grass filter strip (15' with maximum 3:1 slope)
Upstream GIP	Outlet protection may be required at upstream GIP outfall

* Roof drains may bypass the forebay and directly enter the water quality swale with sufficient flow dissipation; however, the forebay volume shall be calculated using the total treatment volume of the GIP.

5.4 Conveyance and Overflow

For On-line infiltration trenches: An overflow structure should always be incorporated into on-line designs to safely convey larger storms through the infiltration trench. Common overflow systems within infiltration trench consist of an overflow structure(s) and/or emergency spillway in compliance with the Stormwater Management Manual, Volume 2, Section 8.

Off-line infiltration trenches: Off-line designs are preferred. One common approach is to create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the facility. In this case, the higher flows do not pass over the stone bed and through the facility.

Another option is to utilize a low-flow diversion or flow splitter at the inlet to allow only the Treatment Volume to enter the facility. This may be achieved with a weir or curb opening sized for the target flow, in combination with a bypass channel. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency.

5.5 Infiltration Trench Material Specifications

Table 4.4 outlines the standard material specifications used to construct infiltration trenches.

Table 4.4. Infiltration Trench Material Specifications

Material	Specification	Notes
Surface Cover	River stone Turf (acceptable with subsurface inflow, ie. roof leader)	Lay a 3-inch layer on the surface of the filter bed in order to suppress weed growth & prevent erosion.
Geotextile	Use a non-woven geotextile fabric with a flow rate of > 110 gal./min./ft^2 (e.g., Geotex 351 or equivalent)	Apply to the sides and below surface cover. AASHTO M288-06, ASTM D4491 & D4751
Choker Layer	#8 or #89 clean washed stone	Meet TDOT Construction Specifications.
Reservoir Layer	#57 or #2 clean washed stone	Meet TDOT Construction Specifications.
Trench Bottom	Coarse sand	Meet TDOT Construction Specifications
Observation Well	6-inch SDR 35 PVC pipe with vented cap and anchor plate	Install one per 50 feet of length of infiltration trench (minimum 1)

SECTION 6: SPECIAL CASE DESIGN ADAPTATIONS

6.1 Shallow Bedrock and Groundwater Connectivity

Many parts of Nashville have shallow bedrock, which can constrain the application of deeper infiltration trenches. In such settings, other GIPs may be more applicable. For more information on bedrock depths download the GIS data set from:

http://water.usgs.gov/GIS/metadata/usgswrd/XML/regolith.xml.

6.2 Karst

Karst regions are found in much of Middle Tennessee, which complicates both land development and stormwater design. While infiltration trenches produce less deep ponding than conventional stormwater practices (e.g., ponds and wetlands); they shall not be used in any area with a high risk of sinkhole formation.

6.3 Hotspots

Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk for spills, leaks or illicit discharges. Infiltration trenches shall not be used in any area with a hotspot designation without appropriate pretreatment and MWS staff approval. Staff may also require additional treatment for runoff from hotspots.

SECTION 7: CONSTRUCTION

7.1 Construction

Construction Stage Erosion and Sediment Controls. Small-scale infiltration trenches areas should be fully protected by perimeter EPSC measures and construction fencing to prevent sedimentation and compaction. Ideally, infiltration trenches should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment.

Excavation. The proposed site should be checked for existing utilities prior to any excavation. It is very important to minimize compaction of the infiltration trench. When possible, excavators should work from the sides of the infiltration trench to remove original soil. If the infiltration trench is excavated using a loader, the contractor must use wide track or marsh track equipment, or light equipment with turf type tires. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high-pressure tires will cause excessive compaction resulting in reduced infiltration rates and is not acceptable. Compaction will significantly contribute to design failure.

The trench excavation should be limited to the width and depth specified in the design. Excavated material should be placed away from the open trench so as not to jeopardize the stability of the trench sidewalls. The sides and bottom of the trench shall be trimmed of all large roots and scarified with no voids prior to backfilling.

7.2 Infiltration Trench Installation

Construction should take place during appropriate weather conditions. The following is a typical construction sequence to properly install an infiltration trench. These steps may be modified to reflect different applications or expected site conditions:

Step 1. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area 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 infiltration trench. 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 2. Ensure that the entire contributing drainage area has been stabilized prior to infiltration trench construction. Otherwise, use EPSC measures as outlined in Section 7.1.

Step 3. Excavation of the infiltration trench should follow the guidelines found in Section 7.1.

Step 4. Remove any roots and scarify the sides and bottom .

Step 5. Install all layers and components of the infiltration trench per the approved plans.

Step 6. Conduct the final construction inspection (see **Section 8**). Then log the GPS coordinates for each infiltration trench and submit them to MWS.

SECTION 8: AS-BUILT REQUIREMENTS

After the infiltration trench has been constructed, the owner/developer must have an as-built certification of the infiltration trench conducted by a registered Professional Engineer. The as-built certification verifies that the GIP was installed per the approved plan. The following items shall be provided in addition to the as-built requirements found in SWMM Volume 1.

1. The Engineer shall include a copy of the GIP summary table found in Appendix 4-D.
2. Supporting documents such as invoices and photographs should be included in the submittal package.

SECTION 9: MAINTENANCE

Each SCM must have a Maintenance Document submitted to Metro for approval and maintained and updated by the SCM owner. Refer to Volume 1, Appendix C for information about the Maintenance Document for infiltration trenches, as well as an inspection checklist. The Maintenance Document must be completed and submitted to Metro with grading permit application. The Maintenance Document is for the use of the SCM owner in performing routine inspections. The developer/owner is responsible for the cost of maintenance and annual inspections. The SCM owner must maintain and update the SCM operations and maintenance plan. At a minimum, the operations and maintenance plan must address:

- Ensure that contributing area, facility and inlets are clear of debris.
- Ensure that the contributing area is stabilized.
- Remove sediment and oil/grease from pretreatment devices, as well as overflow structures.
- Check observation wells following 3 days of dry weather. Failure to percolate within this time period indicates clogging.
- Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.
- Remove trees that start to grow in the vicinity of the trench.
- Replace pea gravel/topsoil and top surface filter fabric (when clogged).
- Perform total rehabilitation of the trench to maintain design storage capacity.
- Excavate trench walls to expose clean soil.

SECTION 10: REFERENCES

Chesapeake Stormwater Network (CSN). 2008. *Technical Bulletin 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed*. Version 1.0. Baltimore, MD. Available online at: http://www.chesapeakestormwater.net/all-things-stormwater/stormwater-guidance-for-karst-terrain-in-the-chesapeake-bay.html

CWP. 2007. *National Pollutant Removal Performance Database, Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

ARC, 2001. Georgia Stormwater Management Manual Volume 2 Technical Handbook.

CDM, 2000. Metropolitan Nashville and Davidson County Stormwater Management Manual Volume 4 Best Management Practices.

Federal Highway Administration (FHWA), United States Department of Transportation. Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring. Accessed January 2006. http://www.fhwa.dot.gov/environment/ultraurb/index.htm.

VADCR. 2011. Stormwater Design Specification No. 8: Infiltration, Version 1.9. Virginia Department of Conservation and Recreation.

VADEQ. 2013. Stormwater Design Specification No. 8: Infiltration, Version 2.0. Virginia Department of Environmental Quality.

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I. Test Pit/Boring Procedures

1. The number of required test pits or standard soil borings is based on proposed infiltration area:
   - **≤50 linear feet = 2 tests**
   - **>50 linear feet = 2 tests + 1 test for every additional 50 linear feet**
2. The location of each test pit or standard soil boring should correspond to the location of the proposed infiltration area and be performed in in situ soils.
3. Excavate each test pit or penetrate each standard soil boring to a depth at least 2 feet below the bottom of the proposed infiltration area.
4. If the groundwater table is located within 2 feet of the bottom of the proposed facility, determine the depth to the groundwater table immediately upon excavation and again 24 hours after excavation is completed.
5. Determine the USDA or Unified Soil Classification system textures at the bottom of the proposed infiltration area and at a depth that is 2 feet below the bottom. All soil horizons should be classified and described.
6. If bedrock is located within 2 feet of the bottom of the proposed infiltration area, determine the depth to the bedrock layer.
7. Test pit/soil boring stakes should be left in the field to identify where soil investigations were performed.

II. Infiltration Testing Procedures

1. The number of required infiltration tests is based on proposed infiltration area:
   - **≤50 linear feet = 2 tests**
   - **>50 linear feet = 2 tests + 1 test for every additional 50 linear feet**
2. The location of each infiltration test should correspond to the location of the proposed infiltration area.
3. Install a test casing (e.g., a rigid, 4 to 6-inch diameter pipe) to the bottom of the proposed infiltration area. Record the testing elevation.
4. Remove all loose material from the sides of the test casing and any smeared soil material from the bottom of the test casing to provide a natural soil interface into which water may percolate. If desired, a 2-inch layer of coarse sand or fine gravel may be placed at the bottom of the test casing to prevent clogging and scouring of the underlying soils. Fill the test casing with clean water to a depth of 2 feet, and allow the underlying soils to presoak for 24 hours.
5. After 24 hours, refill the test casing with another 2 feet of clean water and measure the drop in water level within the test casing after one hour. Repeat the procedure three (3) additional times by filling the test casing with clean water and measuring the drop in water level after one hour. A total of four (4) observations must be completed.
6. The infiltration rate of the underlying soils may be reported either as the average of all four observations or the value of the last observation. The infiltration rate shall be reported in terms of inches per hour along with the elevations and locations of the test pits. Locations shall be shown on site map.
7. Infiltration testing may be performed within an open test pit or a standard soil boring. After infiltration testing is completed, the test casing should be removed, and the test pit or soil boring should be backfilled and restored.

APPENDIX 4-B
STANDARD NOTES

Required Infiltration trench Notes:

- Contractor, Engineer, or Owners Representative shall notify MWS NPDES staff at least 48 hours prior to backfilling the infiltration trench.
- Vehicular and equipment traffic shall be prohibited in the bioretention area to prevent compaction and sediment deposition.

APPENDIX 4-C
STANDARD DETAILS

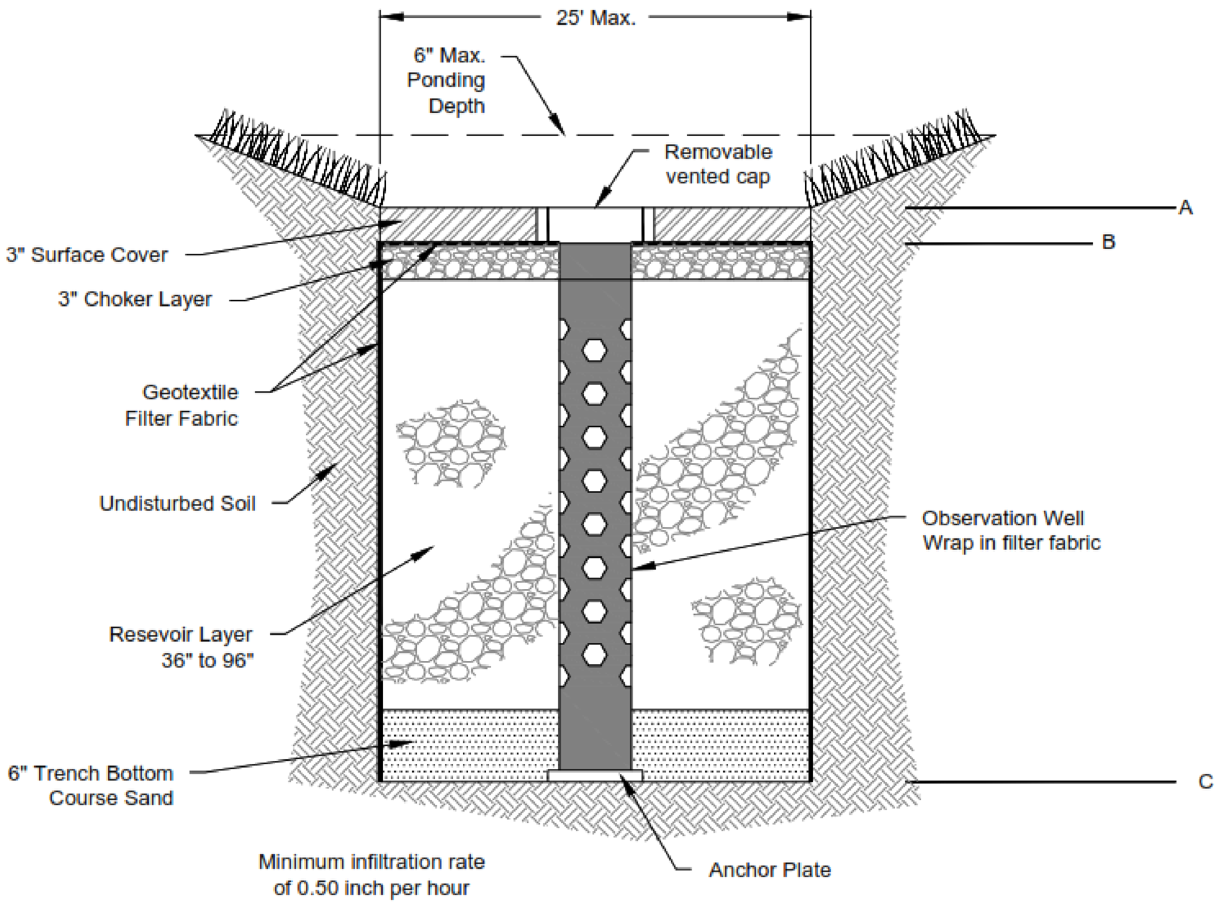

Figure 4.1. Infiltration Trench Section

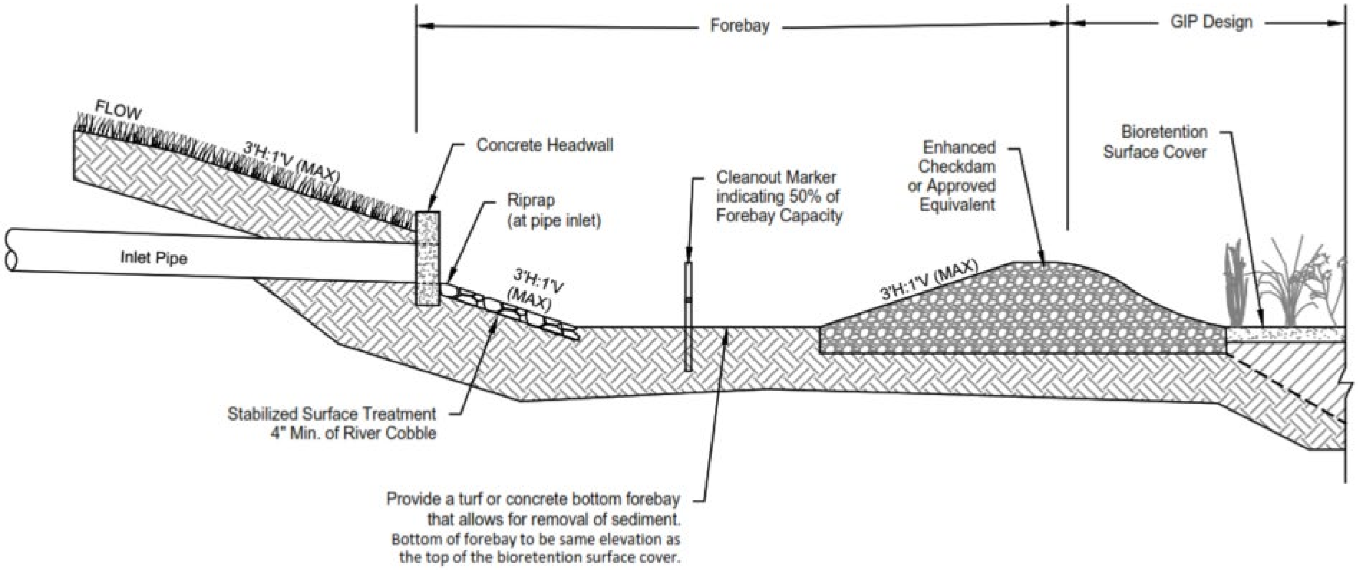

Figure 4.2. Forebay Detail

APPENDIX 4-D
AS-BUILT REQUIREMENTS

A printer friendly version of this table can be found on the MWS Development Services website or by request.

Infiltration Trench Number:

	Design	As-Built
Treatment Volume (Tv), CF		
Surface Area, SF		
Emergency Spillway Elevation*		
Overflow (TOC) Elevation*		
(A) GIP Surface Elevation		
(B) Top of Stone Elevation**		
Outlet Elevation*		
(C) Subgrade Elevation		
* N/A if not required		
** Required if using turf as a surface cover		
ALL Elevation shall be NAVD-88		

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Water Quality Swale

Description: Vegetated open channels designed to capture and infiltrate stormwater runoff within a dry storage layer beneath the base of the channel.

Advantages/Benefits:

- Stormwater treatment combined with conveyance
- Reduced runoff volume
- Reduced peak discharge rate
- Reduced Total Suspended Solids (TSS)
- Reduced pollutant loading
- Reduced runoff temperature
- Groundwater recharge (if soils are sufficiently permeable)
- Reduces runoff velocity
- Promotes infiltration

Disadvantages/Limitations:

- Cannot be used on steep slopes
- High land requirement
- Problems with installation can lead to failure
- Minimum 2 foot separation from groundwater and bedrock is required
- Geotechnical testing required

Selection Criteria:

40% – 60% Runoff Reduction Credit

Land Use Considerations:

- [X] **Residential**
- [X] **Commercial**
- [X] **Industrial**

Maintenance:

- Maintain grass height (if turf)
- Remove sediment from forebay and channel
- Remove accumulated trash and debris
- Re-establish plants as needed

Maintenance Burden: M

L = Low M = Moderate H = High

SECTION 1: DESCRIPTION

Water quality swales are essentially bioretention cells that are shallower, configured as linear channels, and covered with turf or dense, landscape planting. The water quality swale is a soil filter system that temporarily stores and then filters the desired Treatment Volume (T_v). Water quality swales rely on a pre-mixed soil media filter below the channel that is identical to that used for bioretention.

The major design goal for water quality swales is to maximize runoff volume reduction and pollutant removal. To this end, designers may choose to go with the baseline design (Level 1) or choose an enhanced design (Level 2) that maximizes pollutant and runoff reduction. If soil conditions require an underdrain, water quality swales can still qualify for the Level 2 design if they contain a stone storage layer beneath the invert of the underdrain. **Table 5.1** outlines the Level 1 and 2 water quality swale design guidelines. Local simulation modeling supports these runoff reduction credits for the mentioned contributing drainage area (CDA) to surface area ratios.

SECTION 2: PERFORMANCE

The overall runoff reduction capabilities of water quality swales in terms of the Runoff Reduction Method are summarized in **Table 5.1**. Water quality swales create a good environment for runoff reduction, filtration, biological uptake, and microbial activity, and provide high pollutant removal. Water quality swales can become an attractive landscaping feature with high amenity value and community acceptance.

Table 5.1. Runoff Volume Reduction Provided by Water Quality Swales

Stormwater Function	Level 1 Design	Level 2 Design
Runoff Volume Reduction (RR)	40%	60%
Treatment Volume (Tv) Multiplier*	1.0	1.10

*Incorporated into LID Site Design Tool calculations
Sources: CSN (2008) and CWP (2007)

SECTION 3: TYPICAL DETAILS

See Appendix 5-B and 5-C for required standard notes and applicable details for use in construction plans.

SECTION 4: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Water quality swales can be applied in most soils or topography, since runoff simply percolates through an engineered soil bed and can be returned to the stormwater system if the infiltration rate of the underlying soils is low. Key considerations with water quality swales include the following:

Infiltration/Soils. Infiltration is a key component of Low Impact Development (LID) design. Infiltration testing shall be required for all water quality swale locations (see **Section 6.1**). Soil conditions do not constrain the use of water quality swales but can affect the design requirements. Hydrologic Soil Groups (HSG) should be determined from NRCS soil data. For more information on soil types go to: http://websoilsurvey.nrcs.usda.gov/app/. Alternative HSG classifications will be considered when supporting reports from a licensed soil scientist or geotechnical engineer are provided.

Available Space. Planners and designers can assess the feasibility of using water quality swales based on a simple relationship between the contributing drainage area and the corresponding required surface area. Water quality swale footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Water quality swales should be approximately 3% to 10% of the size of the contributing drainage area, depending on the amount of impervious cover.

Accessibility. Water quality swales require periodic maintenance and must be accessible to various types of equipment. A path of travel for equipment no less than twelve feet in width with a maximum slope of 3:1 must be provided for the water quality swale. The path of travel shall be along no less than 50% of the perimeter of the water quality swale and must be accessible by common equipment and vehicles at all times.

Elevation Considerations. Water quality swales are best applied when the grade of contributing slopes is less than 2%. Terracing or other inlet controls may be used to slow runoff velocities entering the facility. Water quality swales are 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 water quality swale into the storm drain system).

Subsurface Constraints. Vertical constraints such as retaining walls, structures, or other impermeable barriers are limited to a maximum of 50% of the water quality swales perimeter. Water quality swales subgrade shall always be separated from the water table and bedrock. Groundwater intersecting the filter bed can lead to possible groundwater contamination or failure of the water quality swales facility. A separation distance of 2 feet is required between the bottom of the excavated water quality swales area and the seasonally high ground water table and/or bedrock.

Utilities. Designers must ensure that future tree canopy growth in the water quality swales area will not interfere with existing overhead public utility lines. Public underground utilities and associated easements shall not be located within the water quality swales footprint. Local utility design guidance shall be consulted in order to determine clearances required between storm water infrastructure and other dry and wet utility lines. Private utilities should not be located within the water quality swale when possible.

Contributing Drainage Area. The maximum impervious contributing drainage area to a water quality swale should be 2.5 acres. When water quality swales treat larger drainage areas, the velocity of flow through the surface channel often becomes too great to treat runoff or prevent erosion in the channel. Similarly, the longitudinal flow of runoff through the soil, stone, and underdrain may cause hydraulic overloading at the downstream sections of the water quality swale.

Hotspot Land Uses. Runoff from hotspot land uses should not be treated with infiltrating water quality swales without appropriate pretreatment and MWS staff approval. For additional information on stormwater hotspots, please consult **Section 7.3**.

Floodplains. Water quality swales shall be constructed outside the limits of the 100-year floodplain. Flood waters from the 100-year event or smaller shall be prohibited from entering the water quality swale underdrain or overflow system.

Irrigation or Baseflow. The planned water quality swale shall not receive baseflow, chlorinated wash-water or other such non-stormwater flows, except for irrigation as necessary during the first growing season for the survival of plantings within the water quality swale (see **Section 10.2**).

Setbacks. It is not recommended to place water quality swales immediately adjacent to structures. To avoid the risk of seepage, a licensed professional engineer should be consulted to determine the appropriate setbacks necessary to prevent water quality swale infiltration from compromising structural foundations or pavement. At a minimum, water quality swales should be located a horizontal distance of 100 feet from any water supply well and 50 feet from septic systems.

Applications. Water quality swales are generally suited for medium-to-high density residential, commercial and institutional developments. It should be noted that special care must be taken to provide adequate pretreatment for water quality swales in space-constrained high traffic areas. Typical locations for water quality swales could include parking lot features and unused pervious areas on a site. Water quality swales are not intended for ROW applications (see GIP-02).

SECTION 5: DESIGN CRITERIA

5.1 Soil Infiltration Rate Testing

One must measure the infiltration rate of subsoils at the subgrade elevation of the water quality swale. If the infiltration rate exceeds 0.5 inch per hour, an underdrain should not be utilized. If the infiltration rate of subsoils is greater than 0.1 inch per hour and less than or equal to 0.5 inch per hour, underdrains will be required. If the infiltration rate is 0.1 inch per hour or less water quality swales shall not be used. On-site soil infiltration rate testing procedures are outlined in **Appendix 4-A**. The number of soil tests varies based on the length of the water quality swale:

- ≤50 linear feet = 2 tests
- >50 linear feet = 2 tests + 1 test for every additional 50 linear feet

A separation distance of 2 feet is required between the bottom of the excavated water quality swale and the seasonally high ground water table and/or bedrock.

For sites with large amounts of cut or fill it may not be practical to perform infiltration testing prior to grading the site. In these cases, a mass grading permit will be required.

5.2 Sizing of Water Quality Swales

5.2.1 Stormwater Quality

Sizing of the surface area (SA) for water quality swales is based on the computed Treatment Volume (T_v) of the contributing drainage area and the storage provided in the facility. The required surface area (in square feet) is computed as the Treatment Volume (in cubic feet) divided by the equivalent storage depth (in feet). The equivalent storage depth is computed as the depth of media, gravel, and surface ponding (in feet) multiplied by the accepted porosity (see **Table 5.2**). All layer depths shall be uniform with regard to surface area. See **Section 6.6** for material specifications.

Table 5.2 Water Quality Swale Typical Section for Water Quality Calculation

Infiltration (i)	i > 0.5"/hr (no underdrain permitted)		0.1"/hr< i ≤0.5"hr (underdrain required)		
Layer	**Level 1 (inches)**	**Level 2 (inches)**	**Level 1 (inches)**	**Level 2 (inches)**	**Porosity Value (n)**
Average Ponding	0-6				1.0
Surface Cover*	Varies				N/A
Media	18-36	24-36	18-36	24-36	0.25
Choker	3	3	3	3	0.40
Reservoir	0-9	9	9	9	0.40
Sump*	0	0	0	12	N/A
* Cannot be used in De and surface area calculations.					

The equivalent storage depth for Level 1 is therefore computed as:

Equation 1.1. Water Quality Swale Level 1 Design Storage Depth

$$\text{Equivalent Storage Depth} = D_E = n_1(D_1) + n_2(D_2) + \cdots$$

$$D_E = (1.5 \text{ to } 3 \text{ ft.} \times 0.25) + (1 \text{ ft} \times 0.40) + (0 \text{ to } 0.5 \text{ ft.} \times 1.0) = 0.78 \text{ to } 1.65 \text{ ft.}$$

Where n_1 and D_1 are for the first layer, etc.

And the equivalent storage depth for Level 2 is computed as:

Equation 1.2. Water quality swale Level 2 Design Storage Depth

$$D_E = (2 \text{ to } 3 \text{ ft.} \times 0.25) + (1 \text{ ft.} \times 0.40) + (0 \text{ to } 0.5 \text{ ft.} \times 1.0) = 0.9 \text{ to } 1.65 \text{ ft.}$$

While this method is simplistic, simulation modeling has proven that it yields a total storage volume equivalent to 80% total average rainfall volume removal for infiltration rates from 0.5 in/hr through 1.2 in/hr.

Therefore, the Level 1 Water quality swale Surface Area (SA) is computed as:

Equation 1.3. Water quality swale Level 1 Design Surface Area

$$SA \text{ (sq. ft.)} = (T_v - \text{the volume reduced by an upstream SCM}) / D_E$$

And the Level 2 Water quality swale Surface Area is computed as:

Equation 1.4. Water quality swale Level 2 Design Surface Area

$$SA \text{ (sq. ft.)} = [(1.10 * Tv) - \text{the volume reduced by an upstream SCM}] / D_E$$

Where:

SA = Minimum surface area of water quality swale filter (sq. ft.)
D_E = *Equivalent Storage Depth (ft.)*
T_v = Treatment Volume (cu. ft.) = $[(1.0 \text{ in.})(R_v)(A)*3630]$

5.2.2 Stormwater Quantity

It is recommended that rain events larger than the 1-inch storm bypass water quality swales to prevent additional maintenance burden. However, if designed with sufficient volume and appropriate outlet structures, peak attenuation control may be provided by the water quality swale. Hydrologic calculations utilizing the SCS method may be necessary to demonstrate pre versus post peak flow rates.

Adjusted CN. With infiltration rates greater than 0.5 inch per hour (see Section 6.1), the removal of volume by water quality swales changes the runoff depth entering downstream flood control facilities. An approximate approach to accounting for the removal of volume is to calculate an "effective SCS curve number" (CN_{adj}), which is less than the actual curve number (CN). CN_{adj} can then be used in hydrologic calculations and in routing. This method is detailed in Volume 5 Section 3.2.5. Additional volume can be provided by increasing the depth of media, stone, or approved proprietary storage products.

5.2.3 Water Quality Swale Geometry

Design guidance regarding the geometry and layout of water quality swales is provided below.

Shape. A trapezoidal shape is preferred for water quality swales for aesthetic, maintenance and hydraulic reasons. Swales should have a bottom width of from 4 to 8 feet 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 berms, check dams, level spreaders or multi-level cross-sections to prevent braiding and erosion of the swale bottom.

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 pretreatment of sheet flows entering the swale.

Swale Longitudinal Slope. The longitudinal slope of the swale should be moderately flat to permit the temporary ponding of the Treatment Volume within the channel. The recommended swale slope is less than or equal to 2% for a Level 1 design and less than or equal to 1% for a Level 2 design. Slopes up to 4% are acceptable if check dams are used. The minimum recommended slope for an on-line water quality swale is 0.5%. Refer to **Table 5.3** for check dam spacing based on the swale longitudinal slope.

Velocity Consideration. The bottom width and slope of a water quality swale should be designed such that the velocity of flow from a 1-inch rainfall will not exceed 3 feet per second. The swale should also convey the 2- and 10-year storms at non-erosive velocities with at least 6 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. Check dams may be used to achieve the needed runoff reduction volume, as well as to reduce velocities.

Table 5.3. Typical Check Dam (CD) Spacing to Achieve Effective Swale Slope

Swale Longitudinal Slope	LEVEL 1	LEVEL 2
	Spacing[1] of 12-inch High (max.) Check Dams[2] to Create an Effective Slope of 2%	Spacing[1] of 12-inch High (max.) Check Dams[2] 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.

[1] The spacing dimension is half of the above distances if a 6-inch check dam is used.
[2] Check dams require a stone energy dissipater at the downstream toe.

Check dams. Check dams must be firmly anchored into the side-slopes to prevent outflanking and be stable during the 10-year storm design event. The height of the check dam relative to the normal channel elevation should not exceed 12 inches. Each check dam should have a minimum of one weep hole or a similar drainage feature so it can dewater after storms. Armoring may be needed behind the check dam to prevent erosion. The check dam must be designed to spread runoff evenly over the water quality swale's filter bed surface, through a centrally located depression with a length equal to the filter bed width. In the center of the check dam, the depressed weir length should be checked for the depth of flow, sized for the appropriate design storm (see **Figure 5.2**). Check dams should be constructed of wood, stone, or concrete.

Ponding Depth. Drop structures or check dams can be used to create ponding cells along the length of the swale. The maximum ponding depth in a swale during the 10-year storm event should not exceed 12 inches at the most downstream point.

5.3 Pretreatment

Pretreatment facilities must always be used in conjunction with water quality swales to remove floatables and sediment to prevent clogging and failure. Every infiltration practice must include multiple pretreatment techniques, although the nature of pretreatment practices depends on the type of flow received. Pretreatment measures should be designed to evenly spread runoff across the entire width of the water quality swale. Several pretreatment measures are feasible, depending on the scale of the water quality swale and whether it receives sheet flow, shallow concentrated flow or deeper concentrated flows. The number, volume and type of acceptable pretreatment techniques needed for the types of receiving flow are found in **Table 5.4**. See Appendix 5-C for applicable details for use in construction plans.

Volumetric pretreatment practices, such as forebays, are sized based on a percentage of the required treatment volume of the GIP. The percentage requirement for the pretreatment practice is exclusive of the required treatment volume for the GIP. Exclusive, in this application, is defined as being separate from the required treatment volume of the GIP. The volume provided by pretreatment practices cannot be included in the calculation for overall treatment volume provided by the GIP.

Table 5.4. Required Pretreatment Elements for Infiltration Practices

Flow Type	Pretreatment Options
*Point/ Concentrated**	• **Forebay** – 15% pretreatment volume (exclusive) – enhanced check dam (TDOT EC-STR-6A); or approved equivalent – flat bottom without stone • **Proprietary structure (MWS approval)**
Sheet	Gravel diaphragm to grass filter strip (15' *with maximum 3:1 slope*)
Upstream GIP	Outlet protection may be required at upstream GIP outfall

* Roof drains may bypass the forebay and directly enter the water quality swale with sufficient flow dissipation; however, the forebay volume shall be calculated using the total treatment volume of the GIP.

5.4 Conveyance and Overflow

For On-line Water Quality Swales: Water quality swales when designed as an on-line practice must have enough capacity to convey runoff from the 100-year design storms at non-erosive velocities, and contain the 10-year flow within the banks of the swale. An overflow structure can be incorporated into on-line designs to safely convey larger storms. Overflow systems within water quality swales should be in compliance with the Stormwater Management Manual, Volume 2, Section 8.

Off-line Water Quality Swales: Off-line designs are preferred. One common approach is to create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the facility. In this case, the higher flows do not pass over the filter bed and through the facility, and additional flow is able to enter as the ponding water filtrates through the soil media.

Another option is to utilize a low-flow diversion or flow splitter at the inlet to allow only the Treatment Volume to enter the facility. This may be achieved with a weir or curb opening sized for the target flow, in combination with a bypass channel. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency.

5.5 Water Quality Swale Material Specifications

Table 5.5 outlines the standard material specifications used to construct water quality swales.

Table 5.5. Water Quality Swale Material Specifications

Material	Specification	Notes
Surface Cover	• River stone • Coir or jute matting • Erosion control matting[1] • Turf	Surface cover can be optional depending on the densities of the plantings provided. [1]Where velocities dictate, use woven biodegradable erosion control matting durable enough to last at least two growing seasons.
Filter Media Composition	Filter Media to contain (by volume): • 70% - 85% sand; • 10%-30% silt + clay, with clay ≤ 10%; and • 5% to 10% organic matter	The volume of filter media based on 110% of the plan volume, to account for settling or compaction. Contact staff for testing procedures.
Geotextile	Use a non-woven geotextile fabric with a flow rate of > 110 gal./min./ft² (e.g., Geotex 351 or equivalent)	Apply only to the sides, above the underdrain (2'-4' wide strip) and beneath the check dams. AASHTO M288-06, ASTM D4491 & D4751
Choker Layer	#8 or #89 clean washed stone	Meet TDOT Construction Specifications.
Reservoir Layer	#57 clean washed stone	Meet TDOT Construction Specifications.
Underdrain	6-inch dual wall HDPE or SDR 35 PVC pipe with 3/8-inch perforations at 6 inches on center	AASHTO M 252 Place perforated pipe at base of reservoir layer.
Cleanout	6-inch SDR 35 PVC pipe with vented cap	Provide cleanouts at the upper end of the underdrain.
Observation Well	6-inch SDR 35 PVC pipe with vented cap and anchor plate	Number of wells equals the number of test pits required for infiltration testing (see Appendix 1-A)
Sump Layer	#57 clean washed stone	Meet TDOT Construction Specifications.
Check Dams	• Wood[1] • Gabions • Rock[2] • Concrete	All check dams shall include weep holes. [1]Wood used for check dams shall consist of pressure treated timers or water-resistant tree species. [2]See TDOT Standard Drawing EC-STR-6.

5.6 Landscaping and Planting Plan

Level 1 water quality swales may utilize turf cover or a landscape plan. A landscaping plan similar to bioretention must be provided for each level 2 water quality swale.

Level 1water quality swales using turf cover should be seeded at such a density to achieve a 90 % turf cover after the second growing season. Performance has been shown to fall rapidly as vegetative cover falls below 80%. Water quality swales should be seeded and not sodded. Seeding establishes deeper roots and sod may have muck soil that is not conducive to infiltration (Storey et. al., 2009). Maximum flow velocities for certain types of turf grass are located in Table 5.6.

Table 5.6. Maximum Permissible Velocities for Turf Cover

Cover Type	Velocity (ft./sec.)
Bermuda grass	4.5
Grass-legume mixture	3
Kentucky bluegrass tall fescue	2.3
Red fescue	1.9

Water quality swales using a landscape plan must address 100% of the planting area and achieve a surface area coverage of at least 75% in the first two years. Designers should choose ornamental grasses, herbaceous plants, or trees that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Minimum landscape plan elements shall include the proposed planting plan for the surface area of the water quality swale, the list of planting stock, sources of plant species, sizes of plants, and the planting sequence along with post-nursery care and initial maintenance requirements. Native plant species are preferred over non-native species, but some ornamental species may be used for landscaping effect if they are not aggressive or invasive. **Appendix 5-D** lists native plant species suitable for use in water quality swales.

Landscaping plans must be prepared by a qualified Landscape Architect. The Landscape Architect shall certify the planting plan with certification statement, located on the water quality swale planting plan. Standard certification statement can be found in **Appendix 5-B**.

SECTION 6: SPECIAL CASE DESIGN ADAPTATIONS

6.1 Shallow Bedrock and Groundwater Connectivity

Many parts of Nashville have shallow bedrock, which can constrain the application of deeper water quality swales (particularly Level 2 designs). In such settings, other GIPs may be more applicable. For more information on bedrock depths download the GIS data set from: http://water.usgs.gov/GIS/metadata/usgswrd/XML/regolith.xml.

6.2 Steep Terrain

In areas of steep terrain, water quality swales can be implemented as long as a multiple cell design is used to dissipate erosive energy prior to filtering. This can be accomplished by terracing a series of water quality swale cells to manage runoff across or down a slope. The drop in elevation between cells should be limited to 1 foot and armored with river stone or a suitable equivalent. A greater emphasis on properly engineered energy dissipaters and/or drop structures is warranted.

6.3 Karst Terrain

Karst regions are found in much of Middle Tennessee, which complicates both land development and stormwater design. Infiltrative practices shall not be used in any area with a high risk of sinkhole formation.

6.4 Hotspots

Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk for spills, leaks or illicit discharges. Water quality swale designs shall not be used in any area with a hotspot designation without appropriate pretreatment, impermeable barriers, and MWS staff approval. Staff may also require additional treatment for runoff from hotspots.

SECTION 7: CONSTRUCTION

7.1 Construction Erosion Prevention and Sediment Control

Construction Stage EPSC Controls. Water quality swales should be fully protected by silt fence or construction fencing, particularly if they will provide an infiltration function (i.e., have no underdrains). Ideally, water quality swale areas should remain *outside* the limits of disturbance during construction to prevent soil compaction by heavy equipment. Sediment traps or basins may be located within the water quality swale excavation limits during construction. However, these must be accompanied by notes and graphic details on the erosion prevention and sediment control (EPSC) plan specifying that the maximum excavation depth at the construction stage must be at least 1 foot above the post-construction subgrade elevation. The plan must also show the proper procedures for converting the temporary sediment control practice to a water quality swale, including dewatering, cleanout and stabilization.

Excavation. The proposed site should be checked for existing utilities prior to any excavation. It is very important to minimize compaction of both the base of the water quality swale and the required backfill. When possible, excavators should work from the sides of the water quality swale to remove original soil. If the water quality swale is excavated using a loader, the contractor must use wide track or marsh track equipment, or light equipment with turf type tires. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high-pressure tires will cause excessive compaction resulting in reduced infiltration rates and is not acceptable. Compaction will significantly contribute to design failure.

7.2 Construction Sequence

The following is a typical construction sequence to properly install a water quality swale, although the steps may be modified to adapt to different site conditions.

Step 1. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area 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 water quality swale. 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 2. Installation should begin after the entire contributing drainage area has been stabilized by vegetation. The designer should check the boundaries of the contributing drainage area to ensure it conforms to original design. Additional EPSC may be needed during swale construction, particularly to divert stormwater from the water quality swale until the filter bed and side slopes are fully stabilized. Pretreatment cells should be excavated first to trap sediments before they reach the planned filter beds.

Step 3. Excavators or backhoes should work from the sides to excavate the water quality swale area to the 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 water quality swale area.

Step 4. The bottom of the water quality swale should be ripped, roto-tilled or otherwise scarified to promote greater infiltration.

Step 5. Place an acceptable filter fabric on the underground (excavated) sides of the water quality swale with a minimum 6-inch overlap. Place the stone needed for storage layer over the filter bed. Perforate the underdrain pipe and check its slope. Add the remaining stone jacket, and then pack #57 stone to 3 inches above the top of the underdrain, and then add 3 inches of choker stone as a filter layer.

Step 6. Add the soil media in 12-inch lifts until the desired top elevation of the water quality swale is achieved. Wait a few days to check for settlement, and add additional media as needed.

Step 7. Install check dams, driveway culverts and internal pretreatment features, as specified in the plan.

Step 8. Install erosion control fabric where needed, spread seed or lay sod, and install any temporary irrigation.

Step 9. Plant landscaping materials as shown in the landscaping plan, and water them weekly during the first 2 months. The construction contract should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.

Step 10. Conduct a final construction inspection and develop a punch list for facility acceptance. Then log the GPS coordinates for each water quality swale and submit them to MWS.

SECTION 8: AS-BUILT REQUIREMENTS

After the water quality swale has been constructed, the owner/developer must have an as-built certification of the water quality swale conducted by a registered Professional Engineer. The as-built certification verifies that the GIP was installed per the approved plan. The following items shall be provided in addition to the as-built requirements found in SWMM Volume 1.

1. Landscape Architect letter certifying that the SCM plantings have been installed in general conformance with the approved grading plans and, with proper maintenance, should achieve 75% coverage within the first two years.
2. The Engineer shall include a copy of the GIP summary table found in Appendix 1-E.
3. Supporting documents such as invoices and media test results shall be included in the submittal package.

SECTION 9: MAINTENANCE

9.1 Maintenance Document

The requirements for the Maintenance Document are in Appendix C of Volume 1 of the Manual. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long-Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities.

9.2. Maintenance Inspections

Annual inspections are used to trigger maintenance operations such as sediment removal, spot revegetation and inlet stabilization. The following is a list of several key maintenance inspection points:

- Add reinforcement planting to maintain 95% turf cover or vegetation density. Reseed or replant any dead vegetation.
- Remove any accumulated sand or sediment deposits on the filter bed surface or in pretreatment cells.
- Inspect upstream and downstream of check dams for evidence of undercutting or erosion, and remove trash or blockages at weepholes.
- Examine filter beds for evidence of braiding, erosion, 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 as needed.
- Look for any bare soil or sediment sources in the contributing drainage area, and stabilize immediately.

Ideally, inspections should be conducted in the spring of each year.

9.3 Routine Maintenance and Operation

Once established, water quality swales have minimal maintenance needs outside of the spring clean-up, regular mowing, and pruning and management of trees and shrubs. The surface of the filter bed can become clogged with fine sediment over time, but this can be alleviated through core aeration or deep tilling of the filter bed. Additional effort may be needed to repair check dams, stabilize inlet points and remove deposited sediment from pretreatment cells.

SECTION 10: REFERENCES

Chesapeake Stormwater Network (CSN). 2008. *Technical Bulletin 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed.* Version 1.0. Baltimore, MD. Available online at: http://www.chesapeakestormwater.net/all-things-stormwater/stormwater-guidance-for-karst-terrain-in-the-chesapeake-bay.html

CWP. 2007. *National Pollutant Removal Performance Database, Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Ellicott City, MD.

Hirschman, D. and J. Kosco. 2008. *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program*. EPA Publication 833-R-08-001, Tetra-Tech, Inc. and the Center for Watershed Protection. Ellicott City, MD.

Maryland Department of Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD. Available online at:

htp:/www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater design/index.asp

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban stormwater retrofit practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Virginia Department of Conservation and Recreation (VADCR). 1999. *Virginia Stormwater Management Handbook. Volumes 1 and 2*. Division of Soil and Water Conservation. Richmond, VA.

Virginia Department of Conservation and Recreation (VADCR). 2011. *Stormwater Design Specification No. 10: Dry Swales. Version 1.9*. Division of Soil and Water Conservation. Richmond, VA.

APPENDIX 5-A
INFILTRATION SOIL TESTING PROCEDURES

I. Test Pit/Boring Procedures

1. The number of required test pits or standard soil borings is based on proposed infiltration area:
   - **≤50 linear feet = 2 tests**
   - **>50 linear feet = 2 tests + 1 test for every additional 50 linear feet**
2. The location of each test pit or standard soil boring should correspond to the location of the proposed infiltration area and be performed in in situ soils.
3. Excavate each test pit or penetrate each standard soil boring to a depth at least 2 feet below the bottom of the proposed infiltration area.
4. If the groundwater table is located within 2 feet of the bottom of the proposed facility, determine the depth to the groundwater table immediately upon excavation and again 24 hours after excavation is completed.
5. Determine the USDA or Unified Soil Classification system textures at the bottom of the proposed infiltration area and at a depth that is 2 feet below the bottom. All soil horizons should be classified and described.
6. If bedrock is located within 2 feet of the bottom of the proposed infiltration area, determine the depth to the bedrock layer.
7. Test pit/soil boring stakes should be left in the field to identify where soil investigations were performed.

II. Infiltration Testing Procedures

1. The number of required infiltration tests is based on proposed infiltration area:
   - **≤50 linear feet = 2 tests**
   - **>50 linear feet = 2 tests + 1 test for every additional 50 linear feet**
2. The location of each infiltration test should correspond to the location of the proposed infiltration area.
3. Install a test casing (e.g., a rigid, 4 to 6-inch diameter pipe) to the bottom of the proposed infiltration area. Record the testing elevation.
4. Remove all loose material from the sides of the test casing and any smeared soil material from the bottom of the test casing to provide a natural soil interface into which water may percolate. If desired, a 2-inch layer of coarse sand or fine gravel may be placed at the bottom of the test casing to prevent clogging and scouring of the underlying soils. Fill the test casing with clean water to a depth of 2 feet, and allow the underlying soils to presoak for 24 hours.
5. After 24 hours, refill the test casing with another 2 feet of clean water and measure the drop in water level within the test casing after one hour. Repeat the procedure three (3) additional times by filling the test casing with clean water and measuring the drop in water level after one hour. A total of four (4) observations must be completed.
6. The infiltration rate of the underlying soils may be reported either as the average of all four observations or the value of the last observation. The infiltration rate shall be reported in terms of inches per hour along with the elevations and locations of the test pits. Locations shall be shown on site map.
7. Infiltration testing may be performed within an open test pit or a standard soil boring. After infiltration testing is completed, the test casing should be removed, and the test pit or soil boring should be backfilled and restored.

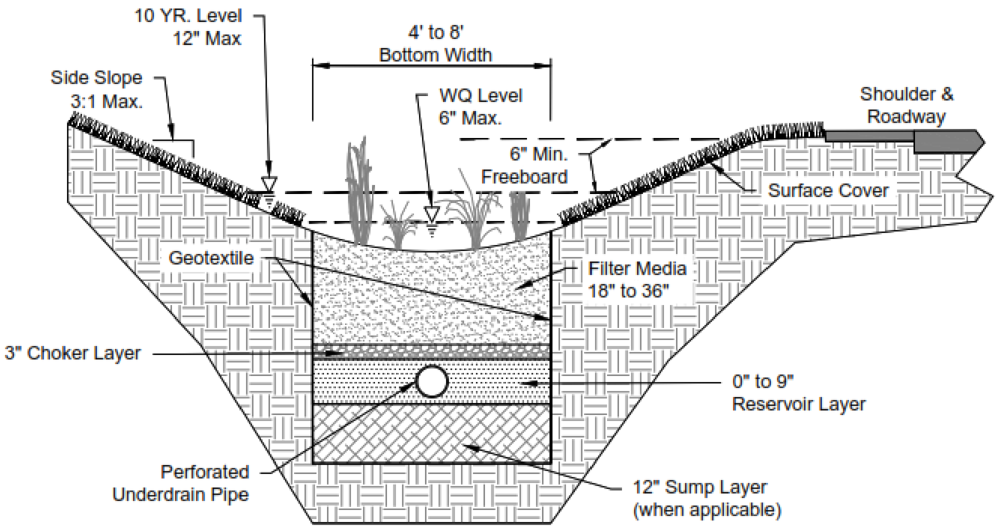
APPENDIX 5-B
STANDARD NOTES

Required Water Quality Swale Notes:

- Contractor, Engineer, or Owners Representative shall notify MWS NPDES Staff at least 48 hours prior to the installation of the planting soil filter bed. At the completion of installation, the above referenced person will collect one sample per water quality swale for analysis and confirmation of the filter media as defined by GIP-05. Media testing not required when using a certified media product.
- I hereby certify that this water quality swale landscape plan is in keeping with the requirements listed in GIP-05 Section 5.7. Only native species and/or non-invasive species of plants were used in the design of this water quality swale landscape plan. This plan will achieve at least 75% surface area coverage within the first two years.
- Vehicular and equipment traffic shall be prohibited in the water quality swale area to prevent compaction and sediment deposition.

APPENDIX 5-C
STANDARD DETAILS

GIP - 05A
WATER QUALITY SWALE
WITH UNDERDRAIN



GIP - 05B
WATER QUALITY SWALE
WITHOUT UNDERDRAIN

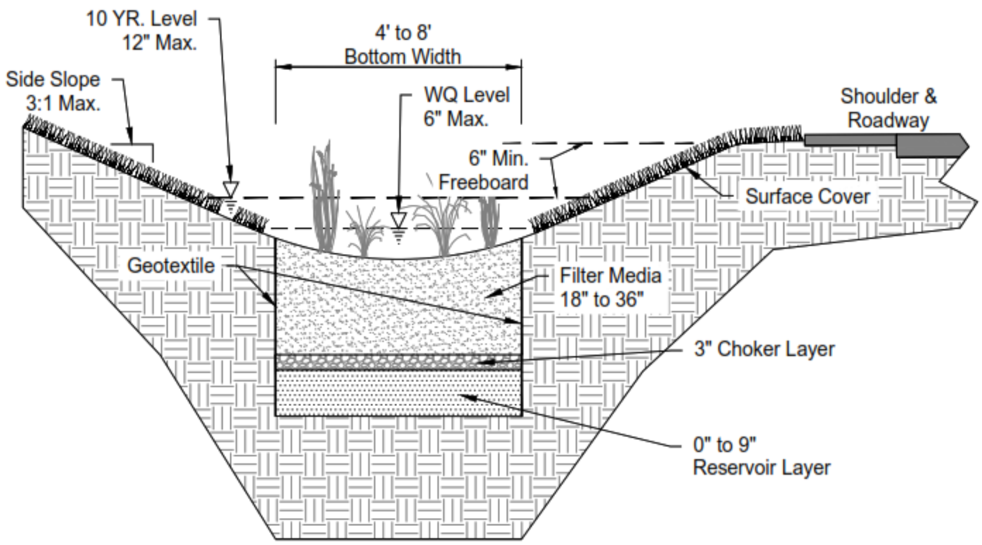


Figure 5.1. Typical Details for Level 1 and 2 Water Quality Swales

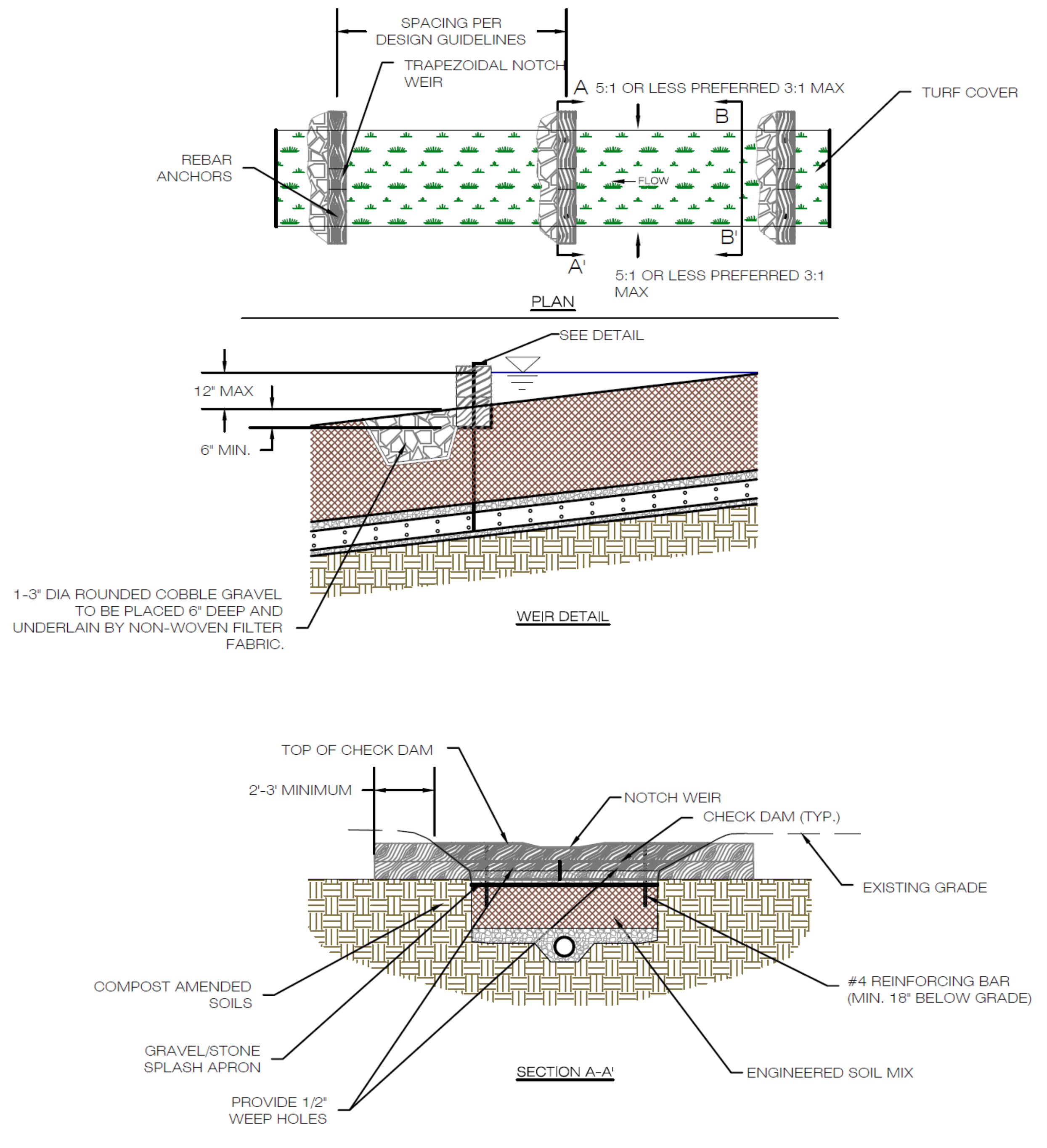


Figure 5.2. Typical Detail for Water Quality Swale Check Dam (source: VADCR, 2011; MWS edited 2020)

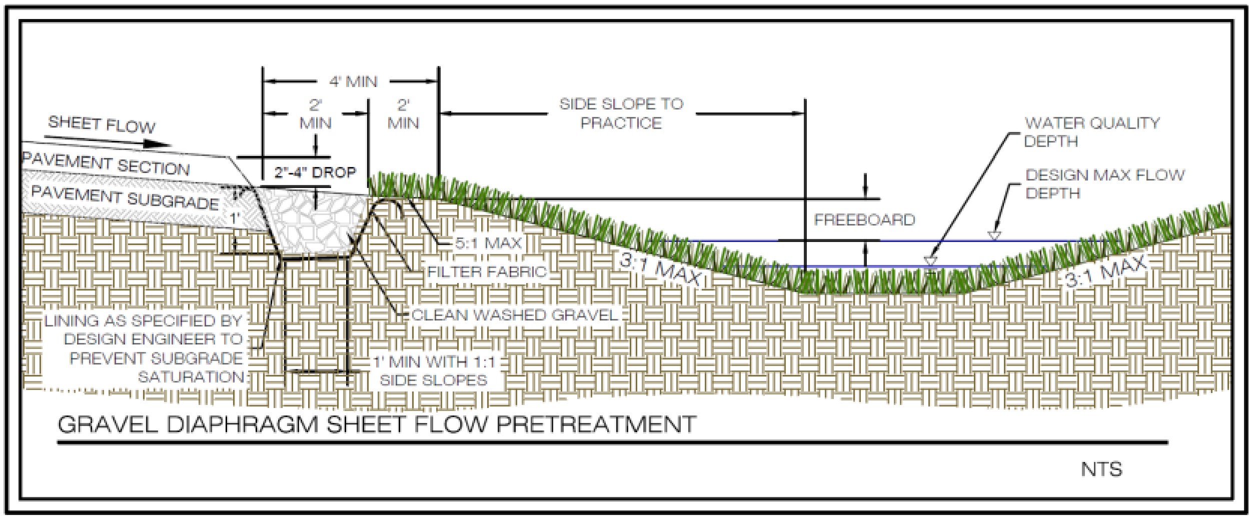


Figure 5.3: Pretreatment – Gravel Flow Spreader for Concentrated Flow (source: VADCR, 2011)

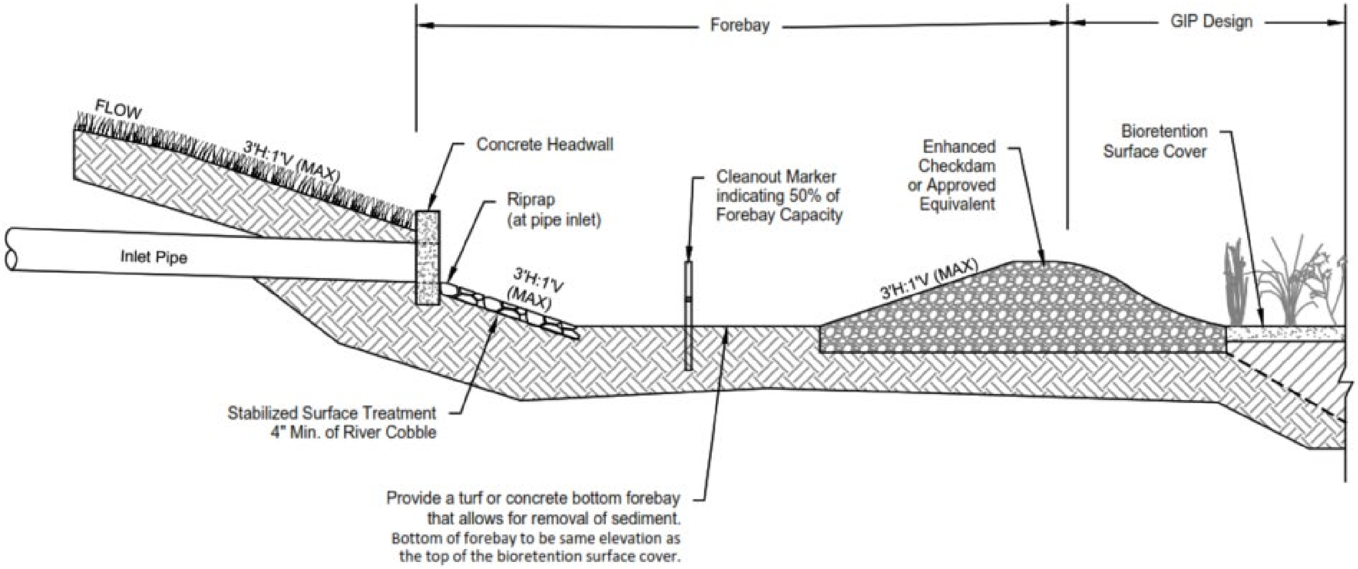


Figure 5.4: Forebay Detail

APPENDIX 5-D
NATIVE PLANTINGS

Popular Native Perennials for Water Quality Swales – Full Sun						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Asclepias incarnate	Marsh milkweed	Plugs – 1 gal.	1 plant/24" o.c.		Pink	3-4'
Asclepias purpurescens	Purple milkweed	Plugs – 1 gal.	1 plant/18" o.c.		Purple	3'
Asclepias syriaca	Common milkweed	Plugs – 1 gal.	1 plant/18" o.c.		Orange	2-5'
Asclepias tuberosa	Butterfly milkweed	Plugs – 1 gal.	1 plant/18" o.c.		Orange	2'
Asclepias verdis	Green milkweed	Plugs – 1 gal.	1 plant/18" o.c.		Green	2'
Asclepias verdicillata		Plugs – 1 gal.	1 plant/18" o.c.		White	2.5'
Aster laevis	Smooth aster	Plugs – 1 gal.	1 plant/18" o.c.		Blue	2-4'
Aster novae-angliae	New England aster	Plugs – 1 gal.	1 plant/24" o.c.		Blue	2-5'
Aster sericeus	Silky aster	Plugs – 1 gal.	1 plant/18" o.c.		Purple	1-2'
Chamaecrista fasciculata	Partridge pea	Plugs – 1 gal.	1 plant/18" o.c.		Yellow	1-2'
Conoclinium coelestinum	Mist flower	Plugs – 1 gal.	1 plant/18" o.c.		Blue	1-2'
Coreopsis lanceolata	Lance-leaf coreopsis	Plugs – 1 gal.	1 plant/18" o.c.		Yellow	6-8'
Echinacea pallida	Pale purple coneflower	Plugs – 1 gal.	1 plant/18" o.c.		Purple	2-3'
Echinacea purpurea	Purple coneflower	Plugs – 1 gal.	1 plant/18" o.c.		Purple	3-4'
Eupatorium perfoliatum	Boneset	Plugs – 1 gal.	1 plant/24" o.c.		White	3-5'
Eupatorium purpureum	Sweet Joe-Pye Weed	Plugs – 1 gal.	1 plant/24" o.c.		Purple	3-6'
Iris virginica	Flag Iris	Plugs – 1 gal.	1 plant/18" o.c.		Blue	2'
Liatris aspera	Rough blazingstar	Plugs – 1 gal.	1 plant/18" o.c.		Purple	2-5'
Liatris microcephalla	Small-headed blazingstar	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	3'
Liatris spicata	Dense blazingstar	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Purple	1.5'
Liatris squarrulosa	Southern blazingstar	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	2-6'
Lobelia cardinalis	Cardinal flower	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Red	2-4'
Monarda didyma	Bee balm	Plugs – 1 gal.	1 plant/24" o.c.	Wet-moist	Red	3'
Monarda fistulosa	Wild bergamot	Plugs – 1 gal	1 plant/18" o.c.		Purple	1-3'
Oenethera fruticosa	Sundrops	Plugs – 1 gal	1 plant/18" o.c.		Yellow	
Penstemon digitalis	Smooth white	Plugs – 1 gal	1 plant/24" o.c.		White	2-3'
Penstemon hirsutus	Hairy beardtongue	Plugs – 1 gal	1 plant/18" o.c.		White	1-3'
Penstemon smallii	Beardtongue	Plugs – 1 gal	1 plant/18" o.c.		Purple	1-2'
Pycanthemum tenuifolium	Slender mountain mint	Plugs – 1 gal	1 plant/18" o.c.		White	1.5-2.5'
Ratibida piñata	Gray-headed coneflower	Plugs – 1 gal	1 plant/18" o.c.		Yellow	2-5'
Rudbeckia hirta	Black-eyed Susan	Plugs – 1 gal	1 plant/18" o.c.		Yellow	3'
Salvia lyrata	Lyre-leaf sage	Plugs – 1 gal	1 plant/18" o.c.		Purple	1-2'
Solidago nemoralis	Gray goldenrod	Plugs – 1 gal.	1 plant/18" o.c.		Yellow	2'
Solidago rugosa	Rough-leaved goldenrod	Plugs – 1 gal.	1 plant/18" o.c.	Wet	Yellow	1-6'
Veronacastrum virginicum	Culver's root	Plugs – 1 gal.	1 plant/24" o.c.	Dry	White	3-6'
Veronia veboracensis	Tall ironweed	Plugs – 1 gal.	1 plant/24" o.c.		Purple	3-4'

Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1

Popular Native Perennials for Water Quality Swales – Shade						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Aquilegia canadensis	Wild columbine	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Pink	1-2.5'
Athyrium filix-femina	Lady Fern	1 gal.	1 plant/18" o.c.	Moist	Green	3'
Arisaema triphyllum	Jack-in-the-pulpit	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Green	1.5-2.5'
Arisaema dricontium	Green dragon	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Green	3'
Asarum canadense	Wild ginger	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Red-brown	0.5-1'
Aster cardifolius	Blue wood aster	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Blue	1-3'
Aster novae-angliae	New England aster	Plugs – 1 gal.	1 plant/24" o.c.	Moist-dry	Blue/ purple	3-4'
Aster oblongifolius	Aromatic Aster	Plugs – 1 gal.	1 plant/24" o.c.	Moist-dry	Blue/ purple	1.5-3'
Coreopsis major	Tickseed coreopsis	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Yellow	3'
Dryopteris marginalis	Shield Fern	1 gal.	1 plant/18" o.c.	Moist	Green	2-3'
Geranium maculatum	Wild geranium	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Pink	2'
Heuchera americana	Alumroot	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	1'
Iris cristata	Dwarf crested iris	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Purple	4"
Lobelia siphilicata	Great blue lobelia	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Blue	1.5-3'
Lobelia cardinalis	Cardinal flower	Plugs – 1 gal.	1 plant/18" o.c.	Wet-moist	Red	2-4'
Mertensia virginica	Virginia bluebells	Plugs – 1 gal.	1 plant/18" o.c.	Moist	Blue	1.5'
Osmunda cinnamomea	Cinnamon Fern	1 gal.	1 plant/24" o.c.	Wet-moist	Green	3-4'
Phlox divericata	Blue phlox	Plugs – 1 gal.	1 plant/18" o.c.	moist	Blue	0.5-2'
Polemonium reptans	Jacob's ladder	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Blue	15"
Polystichum acrostichoides	Christmas fern	Plugs – 1 gal.	1 plant/24" o.c.	Moist-dry	Evergreen	2'
Stylophoru diphyllum	Wood poppy	Plugs – 1 gal.	1 plant/18" o.c.		Yellow	1.5'

Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1.

Popular Native Grasses and Sedges for Water Quality Swales						
Latin Name	**Common Name**	**Size**	**Spacing**	**Moisture**	**Color**	**Height**
Carex grayi	Gray's Sedge	1 gal.	1 plant/24" o.c.	Moist	Green	3'
Carex muskingumensis	Palm Sedge	1 gal.	1 plant/24" o.c.	Moist	Green	3'
Carex stricta	Tussock Sedge	1 gal.	1 plant/24" o.c.	Moist	Green	3-4'
Chasmanthium latifolium	Upland Sea Oats	Plugs – 1 gal.	1 plant/18" o.c.	Moist-dry	Green	4'
Equisetum hyemale	Horsetail	Plugs – 1 gal.	1 plant/18" o.c.	Wet	Green	3'
Juncus effesus	Soft Rush	Plugs – 1 gal.	1 plant/24" o.c.	Wet-dry	Green	4-6'
Muhlenbergia capallaris	Muhly Grass	1 gal.	1 plant/24" o.c.	Moist	Pink	3'
Panicum virgatum	Switchgrass	1-3 gal.	1 plant/48" o.c.	Moist-dry	Yellow	5-7'
Schizachyrium scoparium	Little Blue Stem	1 gal.	1 plant/24" o.c.	Moist-dry	Yellow	3'
Sporobolus heterolepsis	Prairie Dropseed	1 gal.	1 plant/24" o.c.	Moist-dry	Green	2-3'

Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1.

Popular Native Trees for Water Quality Swales							
Latin Name	Common Name	DT-FT	Light	Moisture	Notes	Flower Color	Height
Acer rubrum	Red Maple	DT-FT	Sun-shade	Dry-wet	Fall color		50-70'
Acer saccharum	Sugar Maple		Sun-pt shade	Moist	Fall color		50-75'
Ameleanchier Canadensis	Serviceberry		Sun-pt shade	Moist-wet	Eatable berries	White	15-25'
Asimina triloba	Paw Paw		Sun-pt shade	Moist	Eatable fruits	Maroon	15-30'
Betula nigra	River Birch	FT	Sun-pt shade	Moist-wet	Exfoliating bark		40-70'
Carpinus caroliniana	Ironwood		Sun-pt shade	Moist		White	40-60'
Carya aquatica	Water Hickory	FT-DT	Sun	Moist	Fall color		35-50'
Cercus Canadensis	Redbud	DT	Sun-shade	Moist	Pea-like flowers, seed pods	Purple	20-30'
Chionanthus virginicus	Fringetree		Sun-pt shade	Moist	Panicled, fragrant flowers	White	12-20'
Cladratis lutea	Yellowwood	DT	Sun	Dry-moist	Fall color	White	30-45'
Cornus florida	Flowering Dogwood		Part shade	Moist	Red fruit, wildlife	White	15-30'
Ilex opaca	American Holly	DT	Sun-pt shade	Moist	Evergreen	White	30-50'
Liquidambar styraciflua	Sweetgum	DT-FT	Sun-pt shade	Dry-moist	Spiny fruit		60-100'
Magnolia virginiana	Sweetbay Magnolia		Sun-pt shade	Moist-wet	Evergreen	White	10-60'
Nyssa sylvatica	Black Gum		Sun-Shade	Moist	Fall color		35-50'
Oxydendrum arboretum	Sourwood		Sun-pt shade	Dry-moist	Wildlife	White	20-40'
Platanus occidentalis	Sycamore	FT	Sun-pt shade	Moist	White mottled bark		70-100'
Quercus bicolor	Swamp White Oak	DT	Sun-pt shade	Moist-wet	Acorns		50-60'
Quercus nuttalli	Nuttall Oak	DT	Sun	Dry-moist	Acorns		40-60'
Quercus lyrata	Overcup Oak	FT	Sun	Moist	Acorns		40-60'
Quercus shumardii	Shumard Oak	DT	Sun	Moist	Acorns		40-60'
Rhamnus caroliniana	Carolina Buckthorn		Sun	Moist	Black fruit		15-30'
Salix nigra	Black Willow	FT	Sun-pt shade	Moist-wet	White catkins	Yellow	40-60'
Ulmus americana	American Elm	DT-FT	Sun-pt shade	Moist			
Salix nigra	Black Willow	FT		Moist-wet	White catkins	Yellow	40-60'

Size: min. 2" caliper if not reforestation.
DT: Drought Tolerant FT: Flood Tolerant

Plant material size and grade to conform to "American Standards for Nursery Stock" American Association of Nurserymen, Inc. latest approved revision, ANSI Z-60-1.

APPENDIX 5-E
AS-BUILT REQUIREMENTS

A printer friendly version of this table can be found on the MWS Development Services website or by request.

Forebay Number:

	Design	As-Built
Top of Bank Elevation		
Top of Check Dam		
Bottom of Forebay		
Surface Area, SF		
Pretreatment Volume, CF		
ALL Elevation shall be NAVD88		

Water Quality Swale Number:

	Design	As-Built
Treatment Volume (Tv), CF		
Surface Area, SF		
Top of Bank Elevation		
Channel Slope		
GIP Surface Elevation (Upstream)		
Check Dam Height, FT		
Channel Drop, FT		
GIP Surface Elevation (Downstream)		
Depth of Media, FT		
Depth of Stone, FT		
ALL Elevation shall be NAVD88		

Extended Detention

Description: Constructed stormwater detention basin that has a permanent pool (or micropool). Runoff from each rain event is captured and treated primarily through settling and biological uptake mechanisms.

Advantages/Benefits:

- Can be designed as a multi-functional SCM
- Can be designed as an amenity within a development
- Wildlife habitat potential
- High community acceptance when integrated into a development

Disadvantages/Limitations:

- Potential for thermal impacts downstream
- Prohibited in karst terrain
- Community perceived concerns with mosquitoes and safety

Selection Criteria:

25% Runoff Reduction Credit

Land Use Considerations:

- [x] **Residential**
- [x] **Commercial**
- [x] **Industrial**

Maintenance:

- Remove debris from inlet and outlet structures
- Maintain side slopes/remove invasive vegetation
- Monitor sediment accumulation and remove periodically

M

Maintenance Burden

L = Low   M = Moderate   H = High

SECTION 1: DESCRIPTION

An Extended Detention (ED) Pond relies on 24 to 48-hour detention of stormwater runoff after each rain event. An under-sized outlet structure restricts stormwater flow, so it backs up and is stored within the basin. The temporary ponding enables particulate pollutants to settle out and reduces the maximum peak discharge to the downstream channel. ED ponds rely on gravitational settling as their primary pollutant removal mechanism. Consequently, they generally provide fair-to-good removal for particulate pollutants, but low or negligible removal for soluble pollutants. The use of ED alone generally results in a low overall runoff reduction. As a result, ED is normally combined with other practices to maximize runoff reduction.

SECTION 2: PERFORMANCE

Table 6.1. Runoff Volume Reduction Provided by ED Ponds	
Stormwater Function	**Specified Design**
Runoff Volume Reduction (RR)	25%

Sources: CSN (2008), CWP (2007)

SECTION 3: SCHEMATICS

See Appendix 6-A for schematics for use in sheet flow treatment design.

SECTION 4: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

The following feasibility issues need to be evaluated when ED ponds are considered as the final practice in a treatment train. Many of these issues will be influenced by the type of ED Pond being considered (refer to Design Applications at the end of this section).

Infiltration/Soils. Soil conditions do not constrain the use of ED ponds but can affect the design requirements. Hydrologic Soil Groups (HSG) should be determined from NRCS soil data. For more information on soil types go to: http://websoilsurvey.nrcs.usda.gov/app/. Alternative HSG classifications will be considered when supporting reports from a licensed soil scientist or geotechnical engineer are provided.

Available Space. A typical ED pond requires a footprint of 1% to 3% of its contributing drainage area, depending on the depth of the pond (i.e., the deeper the pond, the smaller footprint needed).

Accessibility. ED ponds require periodic maintenance and must be accessible to various types of equipment. A path of travel for equipment no less than twelve feet in width with a maximum slope of 3:1 must be provided for the ED pond. The path of travel shall be along no less than 50% of the perimeter of the ED pond and must be accessible by common equipment and vehicles at all times.

Elevation Considerations. The depth of an ED pond is usually determined by the amount of hydraulic head available at the site. The bottom elevation is normally the invert of the existing downstream conveyance system to which the ED pond discharges. Typically, a minimum of 6 to 10 feet of head is needed for an ED pond to function.

Subsurface Constraints. ED pond subgrade shall always be separated from the water table and bedrock. A separation distance of 2 feet is required between the bottom of the excavated ED pond and the seasonally high ground water table and/or bedrock.

Utilities. Public underground utilities and associated easements should not be located within the ED pond footprint. Local utility design guidance shall be consulted in order to determine clearances required between stormwater infrastructure and other dry and wet utility lines. Private utilities should not be located within the pond area when possible.

Contributing Drainage Area. A minimum contributing drainage area of 25 acres is recommended for ED ponds.

Micropool applications require a minimum of 10 acres unless water balance calculations support a permanent pool using a smaller drainage area.

Hotspot Land Uses. Runoff from hotspot land uses should not be treated with ED ponds without appropriate pretreatment and MWS staff approval. For additional information on stormwater hotspots, please consult GIP-01, **Section 7.3**.

Floodplains. ED ponds should be constructed outside the limits of the 100-year floodplain. Flood waters from the 100-year event or smaller should be prohibited from entering the ED pond outlet pipe or overflow system.

Setbacks. It is not recommended to place ED ponds immediately adjacent to structures. To avoid the risk of seepage, a licensed professional engineer should be consulted to determine the appropriate setbacks necessary to prevent extended detention pond infiltration from compromising structural foundations or pavement. At a minimum, ED ponds should be located a horizontal distance of 100 feet from any water supply well and 50 feet from septic systems.

Dam Safety. Tennessee Safe Dams Act may apply to ponds with storage volumes and embankment heights large enough to fall under the regulation for dam safety, as applicable. Size emergency spillway for any overtopping of pond in case of rain event in excess of 100-year storm and for instances of malfunction or clogging of primary outlet structure.

Applications. ED ponds can be used at commercial, institutional and residential sites in spaces that are traditionally pervious and landscaped. Extended Detention is normally combined with other stormwater treatment options where a portion of the runoff is directed to bioretention, infiltration, etc. that are within the overall footprint to enhance its performance and appearance. Variations include wet extended detention, micropool extended detention, and multiple pond system.

SECTION 5: DESIGN CRITERIA

5.1 Sizing of Extended Detention Practices

5.1.1 Stormwater Quality

While ED ponds can provide for flood protection, they will rarely provide adequate runoff volume reduction and pollutant removal to serve as a stand-alone compliance strategy. Upland runoff reduction practices can be used to satisfy most or all of the runoff reduction requirements at most sites. Upland runoff reduction practices will greatly reduce the size, footprint and cost of the downstream ED pond.

Runoff treatment (T_v) credit may be taken for the entire water volume below the permanent pool elevation of any micropools, forebays and wetland areas, as well as, the temporary extended detention above the normal pool. A minimum of 40% of the T_v must be designed into the permanent pool. The remaining 60% of the Tv will be contained in a live pool controlled by a low flow orifice. For orifices with diameters less than 3 inches, anti-clogging devices should be used. Low flow orifices can be sized using the following equation:

Equation 6.1. Area of Low Flow Orifice

$$a = \frac{2A(H - H_o)^{0.5}}{3600CT(2g)^{0.5}}$$

Where:

a	=	Area of orifice (ft²)
A	=	Average surface area of the pond (ft²)
C	=	Orifice coefficient, 0.66 for thin, 0.80 for materials thicker than orifice diameter
T	=	Drawdown time of pond (hrs), must be greater than 24 hours
g	=	Gravity (32.2 ft/sec²)
H	=	Elevation when pond is full to storage height (ft)
Ho	=	Final elevation when pond is empty (ft)

5.1.2 Geometry

Side Slopes. Side slopes leading to the ED pond shall have a minimum gradient of 3H:1V. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance.

Long Flow Path. ED pond designs should have an irregular shape and a long flow path from inlet to outlet to increase water residence time, treatment pathways, and pond performance. In terms of flow path geometry, there are two design considerations:

- The overall flow path can be represented as the length-to-width ratio *OR* the flow path. These ratios must be at least 3L:1W. Internal berms, baffles, or topography can be used to extend flow paths and/or create multiple pond cells.
- The shortest flow path represents the distance from the closest inlet to the outlet. The ratio of the shortest flow to the overall length must be at least 0.7. 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 contributing drainage area.

Vertical Extended Detention Limits. The maximum T_v ED water surface elevation may not extend more than 4 feet above the basin floor or normal pool elevation.

No Pilot Channels. Micropool ED ponds shall not have a low flow pilot channel, but instead must be constructed in a manner whereby flows are evenly distributed across the pond bottom, to promote the maximum infiltration possible.

Internal Slope. The maximum longitudinal slope through the pond should be approximately 2% to promote positive flow through the ED pond.

5.1.3 Stormwater Quantity

The outlets must then be sized for appropriate storm events. If the pond is additionally going to address peak flow attenuation, the downstream impacts must be considered for the 2-through 100-year events. Refer to **Volume 2 Chapter 8** for instruction on design of outlet orifices, spillways, and weirs.

5.2 Pretreatment

Sediment forebays are considered to be an integral design feature to maintain the longevity of ED ponds. A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. The total volume of all forebays should be at least 15% of the total Treatment Volume, exclusive.

Volumetric pretreatment practices, such as forebays, are sized based on a percentage of the required treatment volume of the GIP. The percentage requirement for the pretreatment practice is exclusive of the required treatment volume for the GIP. Exclusive, in this application, is defined as being separate from the required treatment volume of the GIP. The volume provided by pretreatment practices cannot be included in the calculation for overall treatment volume provided by the GIP.

SECTION 6: SPECIAL CASE DESIGN ADAPTATIONS

6.1 Karst Terrain

Karst is found in some areas of Metro Nashville. The presence of karst complicates both land development in general and stormwater design in particular. Designers should always conduct geotechnical investigations in karst terrain to assess this risk during the project planning stage. Because of the risk of sinkhole formation and groundwater contamination in karst regions, use of ED ponds is prohibited.

SECTION 7: CONSTRUCTION

7.1 Construction

Construction Stage Erosion and Sediment Controls. ED ponds should be fully protected by silt fence and construction fencing to prevent sedimentation. Sediment traps or basins may be located within the ED pond excavation limits during construction. The plan must also show the proper procedures for converting the temporary sediment control practice to an ED pond, including dewatering, cleanout and stabilization.

Excavation. The proposed site should be checked for existing utilities prior to any excavation.

7.2 ED Pond Installation

Construction should take place during appropriate weather conditions. The following is a typical construction sequence to properly install an ED pond. These steps may be modified to reflect different applications or expected site conditions:

Step 1. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area 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 ED pond. 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 2. Ensure that the entire contributing drainage area has been stabilized prior to ED pond construction. Otherwise, use EPSC measures as outlined in Section 8.1.

Step 3. Excavation of the ED pond.

Step 5. Install all components per plans.

Step 6. Conduct the final construction inspection (see **Section 9**). Then log the GPS coordinates for each ED pond facility and submit them to MWS.

SECTION 8: AS-BUILT REQUIREMENTS

After the extended detention pond has been constructed, the owner/developer must have an as-built certification of the extended detention pond conducted by a registered Professional Engineer. The as-built certification verifies that the GIP was installed per the approved plan. The as-built requirements are found in SWMM Volume 1.

SECTION 9: MAINTENANCE

9.1 Maintenance Document

The requirements for the Maintenance Document are in Appendix C of Volume 1 of the Manual. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities. The property owner must submit annual inspection and maintenance reports to MWS.

9.2 Maintenance Inspections

Maintenance of ED ponds is driven by annual inspections that evaluate the condition and performance of the pond, including the following:

- Measure sediment accumulation levels in forebay.
- Monitor the growth of wetlands, trees and shrubs planted, and note the presence of any invasive plant species.
- Inspect the condition of stormwater inlets to the pond for material damage, erosion or undercutting.
- Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine embankment integrity.
- Inspect pond outfall channel for erosion, undercutting, rip-rap displacement, woody growth, etc.
- Inspect condition of principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, etc.
- Inspect condition of all trash racks, reverse sloped pipes or flashboard risers for evidence of clogging, leakage, debris accumulation, etc.
- Inspect maintenance access to ensure it is free of woody vegetation, and check to see whether valves, manholes and

locks can be opened and operated.
- Inspect internal and external side slopes of the pond for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately.

9.3 Common Ongoing Maintenance Issues

ED ponds are prone to a high clogging risk at the ED low-flow orifice. This component of the pond's plumbing should be inspected at least twice a year after initial construction. The constantly changing water levels in ED ponds make it difficult to mow or manage vegetative growth. The bottom of ED ponds often become soggy, and water-loving trees such as willows may take over. The maintenance plan should clearly outline how vegetation in the pond will be managed or harvested in the future.

The maintenance plan should schedule a cleanup at least once a year to remove trash and floatables that tend to accumulate in the forebay, micropool, and on the bottom of ED ponds.

Frequent sediment removal from the forebay is essential to maintain the function and performance of an ED pond. Maintenance plans should schedule cleanouts every 5 to 7 years, or when inspections indicate that 50% of the forebay capacity has been filled. Sediments excavated from ED ponds are not usually considered toxic or hazardous, and can be safely disposed by either land application or land filling.

SECTION 10: COMMUNITY AND ENVIRONMENTAL CONCERNS

Extended Detention Ponds can generate the following community and environmental concerns that need to be addressed during design.

Aesthetics. ED ponds tend to accumulate sediment and trash, which residents are likely to perceive as unsightly and creating nuisance conditions. Fluctuating water levels in ED ponds also create a difficult landscaping environment. In general, designers should avoid designs that rely solely on *dry* ED ponds.

Existing Wetlands. ED ponds should never be constructed within existing *natural* wetlands, nor should they inundate or otherwise change the hydroperiod of existing wetlands.

Existing Forests. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during design and pond construction. Designers should also be aware that even modest changes in inundation frequency can kill upstream trees (Cappiella *et al.,* 2007).

Safety Risk. ED ponds are generally considered to be safer than other pond options, since they have few deep pools. Steep side-slopes and unfenced headwalls, however, can still create some safety risks. Gentle side slopes should be provided to avoid potentially dangerous drop-offs, especially where ED ponds are located near residential areas.

Mosquito Risk. The fluctuating water levels within ED ponds have potential to create conditions that lead to mosquito breeding. Mosquitoes tend to be more prevalent in irregularly flooded ponds than in ponds with a permanent pool (Santana *et al.*, 1994). Designers can minimize the risk by combining ED with a wet pond or wetland.

SECTION 11: REFERENCES

Chesapeake Stormwater Network (CSN). 2008. *Technical Bulletin 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed.* Version 1.0. Baltimore, MD. Available online at: http://www.chesapeakestormwater.net/all-things-stormwater/stormwater-guidance-for-karst-terrain-in-the-chesapeake-bay.html

Cappiella, K., T. Schueler and T. Wright. 2005. *Urban Watershed Forestry Manual: Part 1: Methods for Increasing Forest Cover in a Watershed* . USDA Forest Service. Center for Watershed Protection. Ellicott City, MD.

Cappiella, K., T. Schueler and T. Wright. 2006. *Urban Watershed Forestry Manual: Part 2: Conserving and Planting Trees at Development Sites*. USDA Forest Service. Center for Watershed Protection. Ellicott City, MD.

Cappiella, K., T. Schueler, J. Tomlinson, T. Wright. 2007. *Urban Watershed Forestry Manual: Part 3: Urban Tree Planting Guide*. USDA Forest Service. Center for Watershed Protection. Ellicott City, MD.

Cappiella, K., L. Fraley-McNeal, M. Novotney and T. Schueler. 2008. "The Next Generation of Stormwater Wetlands." *Wetlands and Watersheds Article No. 5*. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection. 2004. *Pond and Wetland Maintenance Guidebook*. Ellicott City, MD.

CWP. 2007. *National Pollutant Removal Performance Database, Version 3.0*. Center for Watershed Protection, Ellicott City, MD

Chesapeake Stormwater Network (CSN). 2008. *Technical Bulletin 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed.* Version 1.0. Baltimore, MD.

Chesapeake Stormwater Network (CSN). 2009. Technical Bulletin No. 1. Stormwater Guidance for Karst Terrain in the Chesapeake Bay Watershed, Version 2.0. Retrieved from www.chesapeakestormwater.net/all-things-stormwater/category/policy-design-issues.

Hirschman, D., L. Woodworth and S. Drescher. 2009. *Technical Report: Stormwater BMPs in Virginia's James River Basin: An Assessment of Field Conditions & Programs*. Center for Watershed Protection. Ellicott City, MD.

Maryland Department of Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD. Available online at: www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater design/index.asp.

Santana, F.J., J.R. Wood, R.E. Parsons, & S.K. Chamberlain. 1994. Control of Mosquito Breeding in Permitted Stormwater Systems. Brooksville: Sarasota County Mosquito Control and Southwest Florida Water Management District.

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Virginia Department of Conservation and Recreation (VADCR). 1999. *Virginia Stormwater Management Handbook. Volumes 1 and 2*. Division of Soil and Water Conservation. Richmond, VA.

Virginia Department of Conservation and Recreation (VADCR). 2011. *Virginia DCR Stormwater Design Specification No. 15, Extended Detention (ED) Pond, Version 1.9, March 1, 2011*. Division of Soil and Water Conservation. Richmond, VA.

APPENDIX 6-A
SCHEMATICS

Figure 6.1 portrays a typical schematic for an ED pond.

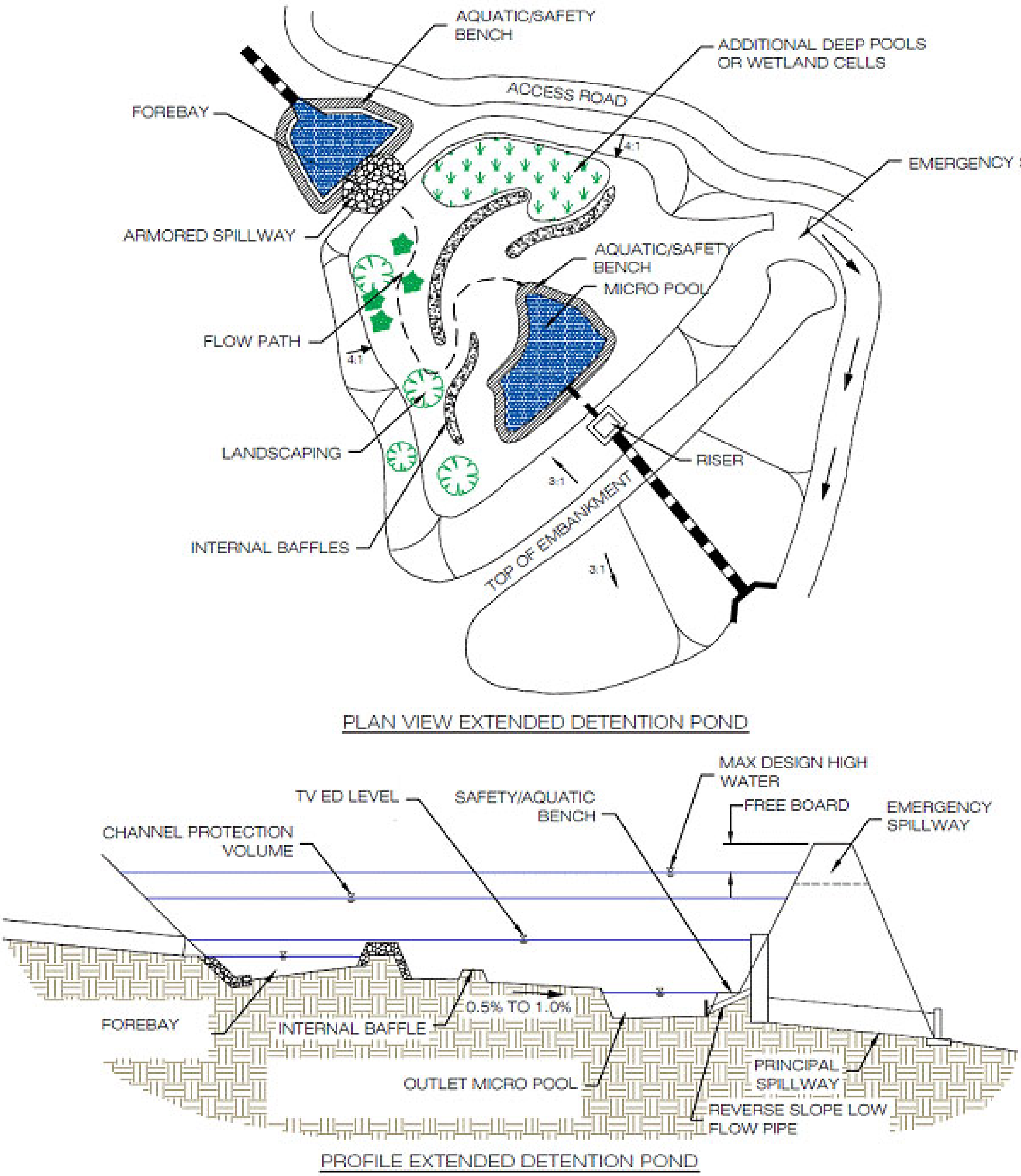


Figure 6.1. Typical Extended Detention Pond Details (source: VADCR, 2011)

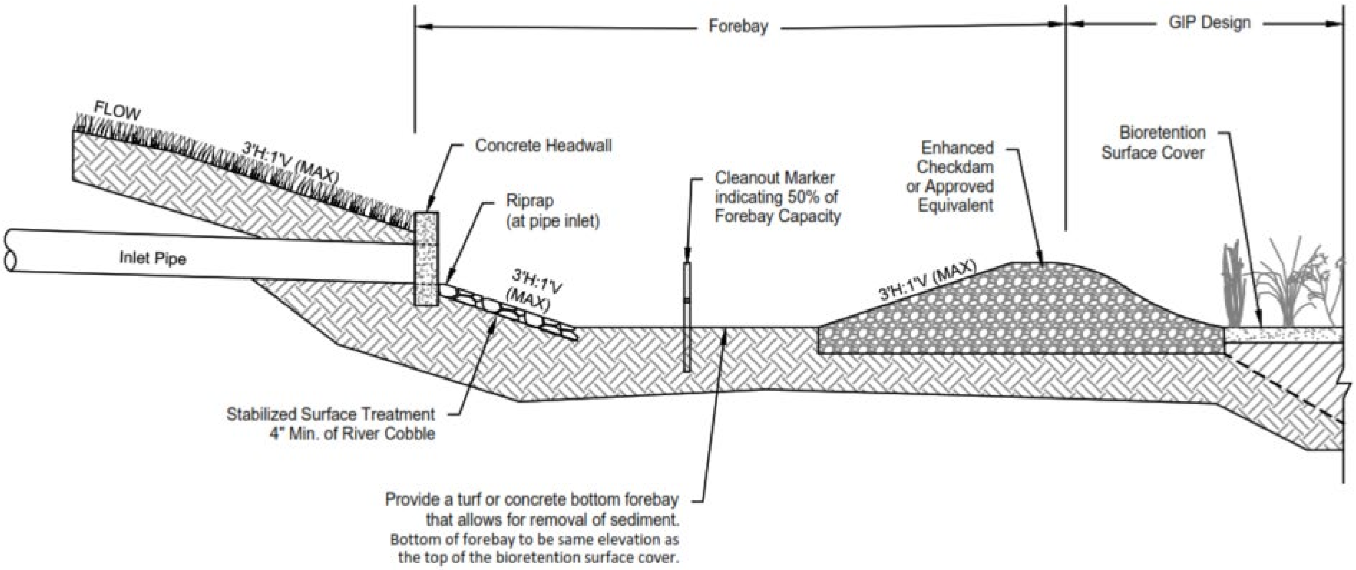


Figure 6.2. Forebay Detail

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Grass Channel

Description: Limited application structural control intended for small drainage areas. Open channels that are vegetated and are designed to filter stormwater runoff through settling and biological uptake mechanisms, as well as to slow water for treatment by another structural control.

Advantages/Benefits:

- Provides pretreatment if used as part of runoff conveyance system
- Cost effective – less expensive than curb and gutter
- Good for small drainage areas
- Generally used in conjunction with downstream practices to increase runoff reduction

Disadvantages/Limitations:

- Must be carefully designed to achieve low, non-erosive flow rates in the channel
- May re-suspend sediment
- Due to potential standing water in channels increased maintenance may be required.
- Will not receive additional runoff reduction credit if more than one grass channel is used in a series

Selection Criteria:

10% – 20% Runoff Reduction Credit for HSG soils C and D

20% – 30% Runoff Reduction Credit for HSG Soils A and B

Land Use Considerations:

- [x] **Residential**
- [x] **Commercial**
- [x] **Industrial**

Maintenance:

- Monitor sediment accumulation and periodically clean out
- Inspect for and correct formation of rills and gullies
- Remove debris from inlet and outlet structures
- Maintain side slopes/remove invasive vegetation
- Ensure that vegetation is well-established

Maintenance Burden: L

L = Low M = Moderate H = High

SECTION 1. DESCRIPTION

Grass channels are conveyance channels that are designed to provide some treatment of runoff, as well as to slow down runoff velocities for treatment in other structural controls. Grass channels are appropriate for a number of applications including treating runoff from paved roads and from other impervious areas.

Grass channels can provide runoff filtering within the stormwater conveyance system resulting in the delivery of less pollutants than a traditional system of curb and gutter, storm drain inlets and pipes. The performance of grass channels will vary depending on the underlying soil permeability as shown in **Table 7.1**. Grass channels, however, are not capable of providing the same stormwater functions as water quality swales as they lack the storage volume associated with the engineered soil media. Their runoff reduction performance can be increased when compost amendments are added to the bottom of the channel (See **Appendix 7-A**). Grass channels are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system, where development density, topography and soils permit.

SECTION 2. PERFORMANCE

Table 7.1. Runoff Volume Reduction Provided by Grass Channels[1]

Stormwater Function	Level 1 HSG Soils C and D		Level 2 HSG Soils A and B	
	No CA[2]	With CA	No CA[2]	With CA[3]
Runoff Volume Reduction (RR)	10%	20%	20%	30%[3]
Will not receive additional runoff reduction credit if more than one grass channel is used in a series				

[1] CSN (2008) and CWP (2007).
[2] CA= Compost Amended Soils, see Appendix 7-A
[3] Compost amendments are generally not applicable for A and B soils, although it may be advisable to incorporate them on mass-graded and/or excavated soils to maintain runoff reduction rates. In these cases, the 30% runoff reduction rate may be claimed, regardless of the pre-construction HSG.

SECTION 3: TYPICAL DETAILS

See Appendix 7-B for required standard applicable details for use in construction plans.

SECTION 4: PHYSICAL FEASIBILITY AND DESIGN APPLICATIONS

Grass channels can be implemented on development sites where development density, topography and soils are suitable. The linear nature of grass channels makes them well-suited to treat highway runoff, low and medium density residential road runoff and small commercial parking areas or driveways. Key considerations for grass channels include:

Soils. Grass channels can be used on most soils with some restrictions on the most impermeable soils. Grass channels situated on Hydrologic Soil Group C and D soils will require compost amendments in order to improve performance.

Available Space. Grass channels can be incorporated into linear development applications (e.g., roadways) by utilizing the footprint typically required for an open section drainage feature. The footprint required will likely be greater than that of a typical conveyance channel (TDOT or equivalent). However, the benefit of the runoff reduction may reduce the footprint requirements for stormwater management elsewhere on the development site.

Accessibility. Grass channels require periodic maintenance and must be accessible to various types of equipment. A path of travel for equipment no less than twelve feet in width with a maximum slope of 3:1 must be provided for the grass channel. The path of travel shall be along no less than 50% of the perimeter of the grass channel and must be accessible by common equipment and vehicles at all times.

Elevation Considerations. Grass channels are best applied when the grade of contributing slopes is less than 4%. Terracing or other inlet controls may be used to slow runoff velocities entering the facility. Grass channels are fundamentally constrained by the invert elevation of the existing conveyance system to which the practice discharges.

Subsurface Constraints. Grass channels subgrade should be separated from the water table and bedrock. A separation distance of 2 feet is recommended between the bottom of the excavated grass channels and the seasonally high ground water table and/or bedrock.

Utilities. Public underground utilities and associated easements should not be located within the grass channel footprint. Local utility design guidance shall be consulted in order to determine clearances required between stormwater infrastructure and other dry and wet utility lines. Private utilities should not be located within the grass channel when possible.

Contributing Drainage Area. The drainage area (contributing or effective) to a grass channel must be 5 acres or less. When grass channels treat and convey runoff from drainage areas greater than 5 acres, the velocity and flow depth through the channel becomes too great to treat runoff or prevent channel erosion.

Floodplains. Grass channels should be constructed outside the limits of the 100-year floodplain.

Setbacks. Grass channels should be set back at least 10 feet down-gradient from building foundations, 50 feet from septic system fields and 100 feet from private wells.

Applications. Grass channels can be used in residential, commercial or institutional development settings. Large commercial site applications may require multiple channels in order to effectively break up the drainage areas and meet the design criteria. Grass channels within the right of way will only receive credit for treating stormwater generated within the right of way. Right of way applications will require Metro Water Services and Metro Public Works approval.

SECTION 5: DESIGN CRITERIA

5.1 Sizing of Grass Channels

5.1.1 Stormwater Quality

Unlike volumetric stormwater practices, grass channels are designed based on a peak rate of flow of the contributing drainage area and achieve a minimum residence time of 5 minutes. The lengths of grass channels vary based on the drainage area imperviousness and slope. Channels must be no less than 25 feet long. **Table 7.2** below gives the minimum lengths for grass channels based on slope and percent imperviousness. Flow being treated by the grass channel must traverse the minimum channel length.

Table 7.2 Grass Channel Length Guidance[1]

Contributing Drainage Area	<=33% Impervious		Between 34% and 66% Impervious		>=67% Impervious	
Slope (max = 4%)	< 2%	> 2%	< 2%	> 2%	< 2%	> 2%
Grass channel minimum length (feet)	25	40	30	45	35	50

[1] Source: ARC (2001)

5.1.2 Geometry

Design guidance regarding the geometry and layout of grass channels is provided below. See Stormwater Management Manual, Volume 2 for channel hydraulic calculations.

Shape. A trapezoidal shape is preferred for grass channels for aesthetic, maintenance and hydraulic reasons. The bottom width of the channel should be between 4 to 8 feet wide. If a channel 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 channel bottom. The bottom width is a dependent variable in the calculation of velocity based on Manning's equation.

Side Slopes. Grass channel side slopes should be no steeper than 3 H:1 V for ease of mowing and routine maintenance. Flatter slopes are encouraged, where adequate space is available, to aid in pretreatment of sheet flows entering the channel.

Channel Longitudinal Slope. The longitudinal slope of the channel should ideally be between 1% and 2% in order to avoid scour and short-circuiting within the channel. Longitudinal slopes up to 4% are acceptable; however, check dams will likely be required in order to meet the allowable maximum flow velocities.

Velocity Consideration. The bottom width and slope of a grass channel should be designed such that the flow velocities are minimized to allow for pollutants to settle out. The flow depth for the peak treatment volume should be maintained at 3" or less. The channel should also convey larger storms at non-erosive velocities with at least 6 inches of freeboard. Refer to **Table 7.3** for the maximum velocities per type of turf grass. 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. Check dams may be used to achieve the 5-minute minimum residence time.

Table 7.3: Maximum Permissible Velocities for Grass Channels

Cover Type	Erosion Resistant Soils (ft./sec.)	Easily Eroded Soils (ft./sec.)
Bermuda grass	6	4.5
Kentucky bluegrass	5	3.8
Grass-legume mixture	4	3
Tall fescue	3	2.3
Red fescue	2.5	1.9

Sources: VADCR (1992), Ree (1949), Temple et al (1987)

Check dams. Check dams must be firmly anchored into the side-slopes to prevent outflanking and be stable during the 10-year storm design event. The height of the check dam relative to the normal channel elevation should not exceed 12 inches. Check dams should be constructed of wood, stone, or concrete. Each impermeable check dam should have a minimum of one weep hole or a similar drainage feature so it can dewater after storms. The orifice equation should be utilized to show that minimum residence time is achieved. If rock check dams are utilized, see TDOT Standard Drawing EC-STR-6 for spacing to meet minimum residence time.

Armoring may be needed behind the check dam to prevent erosion. The check dam must be designed to spread runoff evenly over the grass channel, through a centrally located depression with a length equal to the bottom width. In the center of the check dam, the depressed weir length should be checked for the depth of flow, sized for the appropriate design storm (see **Figure 7A.3**). The ponded water at a downhill check dam should not touch the toe of the upstream check dam.

5.2 Pretreatment

Pretreatment measures should be designed to evenly spread runoff across the entire width of the grass channel. Several pretreatment measures are feasible, depending on the scale of the grass channel and whether it receives sheet flow, shallow concentrated flow or deeper concentrated flows.

5.3 Compost Soil Amendments

Soil compost amendments serve to increase the runoff reduction capability of a grass channel. The compost-amended strip should extend over the length and width of the channel bottom, and the compost should be incorporated to a depth as outlined in **Appendix 7-A**. The amended area will need to be rapidly stabilized with grass. Depending on the slope of the channel, it may be necessary to install a protective biodegradable geotextile fabric to protect the compost-amended soils. Care must be taken to consider the erosive characteristics of the amended soils when selecting an appropriate geotextile. For redevelopment or retrofit applications, the final elevation of the grass channel (following compost amendment) must be verified as meeting the original design hydraulic capacity.

5.4 Planting Grass Channels

Designers should choose grass species that can withstand both wet and dry periods as well as relatively high-velocity flows within the channel. Taller and denser grasses are preferable, though the species of grass is less important than good stabilization. Grass channels should be seeded at such a density to achieve a 90% turf cover after the second growing season. Performance has been shown to fall rapidly as vegetative cover falls below 80%. Grass channels should be seeded and not sodded. Seeding establishes deeper roots and sod may have muck soil that is not conducive to infiltration (Storey et. al., 2009).

5.5 Grass Channel Material Specifications

The basic material specifications for grass channels are outlined in **Table 7.4** below.

Table 7.4. Grass Channel Material Specifications

Material	Specification	Notes
Surface Cover	• Bermuda grass • Grass-legume mixture • Kentucky bluegrass • Tall fescue • Red fescue	Where velocities dictate, use woven biodegradable erosion control matting durable enough to last at least two growing seasons.
Compost Soil Amendment	See App. 7-A for additional requirements	
Check Dams	• Wood[1] • Gabions • Rock[2] • Concrete	[1]Wood used for check dams shall consist of pressure treated timers or water-resistant tree species. [2]See TDOT Standard Drawing EC-STR-6.

SECTION 6: SPECIAL CASE DESIGN ADAPTATIONS

6.1 Steep Terrain

Grass channels are not practical in areas of steep terrain, although terracing a series of grass channel 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.

SECTION 7: CONSTRUCTION

7.1 Construction Erosion Prevention and Sediment Control

Construction Stage EPSC Controls. Grass channels should be fully protected by check dams. Ideally, grass channels should remain *outside* the limits of disturbance during construction to prevent soil compaction by heavy equipment.

Excavation. The proposed site should be checked for existing utilities prior to any excavation. It is very important to minimize compaction of both the base of the grass channel and the amended soils. When possible, excavators should work from the sides to remove original soil.

7.2 Construction Sequence

The following is a typical construction sequence to properly install a grass channel, although steps may be modified to reflect different site conditions.

Step 1. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area 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 grass channel. 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 2. Grass channel installation may only begin after the entire contributing drainage area has been stabilized with vegetation. Any accumulation of sediments that does occur within the channel must be removed during the final stages of grading to achieve the design cross-section. EPSC for construction of the grass channel should be installed as specified in the erosion and sediment control plan. Stormwater flows must not be permitted into the grass channel until the bottom and side slopes are fully stabilized.

Step 3. Grade the grass channel to the final dimensions shown on the plan.

Step 4. Install check dams and pretreatment features as shown on the plan.

Step 5 (Optional). Incorporate compost amendments according to **Appendix 7-A**.

Step 6. Hydro-seed the bottom and banks of the grass channel, and peg in erosion control fabric or blanket where needed. After initial planting, a biodegradable erosion control fabric should be used, conforming to soil stabilization blanket and matting requirements found in the Tennessee Erosion and Sediment Control Handbook.

Step 7. Conduct the final construction inspection and develop a punch list for facility acceptance. Then log the GPS coordinates for each grass channel and submit them to MWS.

SECTION 8: AS-BUILT REQUIREMENTS

After the grass channel has been constructed, the owner/developer must have an as-built certification of the grass channel conducted by a registered Professional Engineer. The as-built certification verifies that the GIP was installed per the approved plan. The following items shall be provided in addition to the as-built requirements found in SWMM Volume 1.

1. The Engineer shall include a copy of the GIP summary table found in Appendix 7-C.
2. Supporting documents such as invoices and compost certification.

SECTION 9: MAINTENANCE

9.1 Maintenance Document

The requirements for the Maintenance Document are in Appendix C of Volume 1 of the Manual. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long-Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities. The property owner must submit annual inspection and maintenance reports to MWS.

Maintenance requirements for grass channels include the following:

1. Maintain grass height of 3 to 4 inches.
2. Remove sediment build up in channel bottom when it accumulates to 25% of original total channel volume.
3. Ensure that rills and gullies have not formed on side slopes. Correct if necessary.
4. Remove trash and debris build up.
5. Replant areas where vegetation has not been successfully established.

All grass channels must be covered by a drainage easement to allow inspection and maintenance. If a grass channel is located in a residential private lot, the existence and purpose of the grass channel shall be noted on the deed of record.

9.2 Ongoing Maintenance

Once established, grass channels have minimal maintenance needs outside of the spring cleanup, regular mowing, repair of check dams and other measures to maintain the hydraulic efficiency of the channel and a dense, healthy grass cover.

Table 7.5 Suggested Spring Maintenance Inspections/Cleanups for Grass Channels[1]

Activity
Add reinforcement planting to maintain 90% turf cover. Reseed any dead vegetation.
Remove any accumulated sand or sediment deposits behind check dams.
Inspect upstream and downstream of check dams for evidence of undercutting or erosion, and remove and trash or blockages at weepholes.
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.
Look for any bare soil or sediment sources in the contributing drainage area and stabilize immediately.

[1] Source: VADCR (2011)

Figure 7.1: Typical Grass Channel
Rosa Parks Boulevard, Nashville, TN

SECTION 10: REFERENCES

Atlanta Regional Commission (ARC). 2001. *Georgia Stormwater Management Manual.* Atlanta, GA.

Chesapeake Stormwater Network (CSN). 2008. *Technical Bulletin 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed.* Version 1.0. Baltimore, MD. Available online at: http://www.chesapeakestormwater.net/all-things-stormwater/stormwater-guidance-for-karst-terrain-in-the-chesapeake-bay.html

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Ellicott City, MD.

CWP. 2007. *National Pollutant Removal Performance Database Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Haan, C.T., Barfield, B.J., and Hayes, J.C. *Design Hydrology and Sedimentology for Small Catchments*. Academic Press, New York, 1994.

Lantin, A., and M. Barrett. 2005. *Design and Pollutant Reduction of Vegetated Strips and Swales*. ASCE. Downloaded September, 2005.

Maryland Department of Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD. Available online at: htp:/www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater design/index.asp

Northern Virginia Regional Commission (NOVA). 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook*. Fairfax, Virginia

Ree, W. 1949. *Hydraulic characteristics of vegetation for vegetated waterways.* Agricultural Engineering.

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Storey, B.J., Li, M., McFalls, J.A., Yi, Y. 2009. *Stormwater Treatment with Vegetated Buffers.* Texas Transportation Institute. College Station, TX.

Temple, D.M., Robinson, K.M., Ahring, R.M., and Davis, A.G. 1987 "Stability design of grass-lined open channels." Agric. Handbook 667, Agric. Res. Service, U.S. Department of Agriculture, Washington, D.C.

Virginia Department of Conservation and Recreation (VADCR). 2011. Stormwater Design Specification No. 3: Grass Channel, Version 2.3, March 1, 2011. http://vwrrc.vt.edu/swc/NonProprietaryBMPs.html.

Virginia Department of Conservation and Recreation (VADCR). 1992. *Virginia Erosion and Sediment Control Handbook*

Virginia Department of Conservation and Recreation (VADCR). 1999. *Virginia Stormwater Management Handbook. Volumes 1 and 2*. Division of Soil and Water Conservation. Richmond, VA.

Wisconsin Department of Natural Resources. "Vegetated Infiltration Swale (1005)." *Interim Technical Standard, Conservation Practice Standards*. Standards Oversight Council, Madison, Wisconsin, 2004. Available online at: http://dnr.wi.gov/org/water/wm/nps/pdf/stormwater/techstds/post/InterimInfiltrationSwale100 5. pdf.

APPENDIX 7-A
DESIGN CRITERIA FOR AMENDING SOILS WITH COMPOST

SECTION 1: DESCRIPTION

Soil restoration is a practice 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 runoff reduction performance.

SECTION 2: DESIGN CRITERIA

2.1 Determining Depth of Compost Incorporation

Table 7-A.1 presents some general guidance for compost amendments and incorporation depths.

Table 7-A.1. Compost and Incorporation Depths		
	Level 1	**Level 2**
Compost (in)	6	12
Incorporation Depth (in)	12	24
Incorporation Method	Tiller	Subsoiler

Once the area and depth of the compost amendments are known, the designer can estimate the total amount of compost needed using the following estimator equation:

Equation 7.1. Compost Quantity Estimation

$$C = A * D * 0.0031$$

Where: C = compost needed (cu. yds.)

A = area of soil amended (sq. ft.)

D = depth of compost added (in.)

2.2 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.ft.

APPENDIX 7-B
STANDARD DETAILS

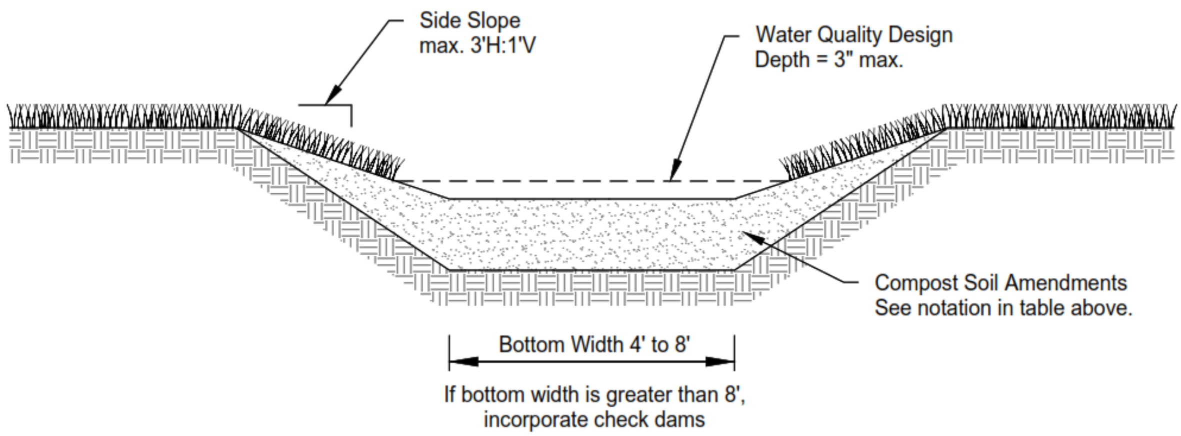

Figure 7A.1. Grass Channel – Typical Section

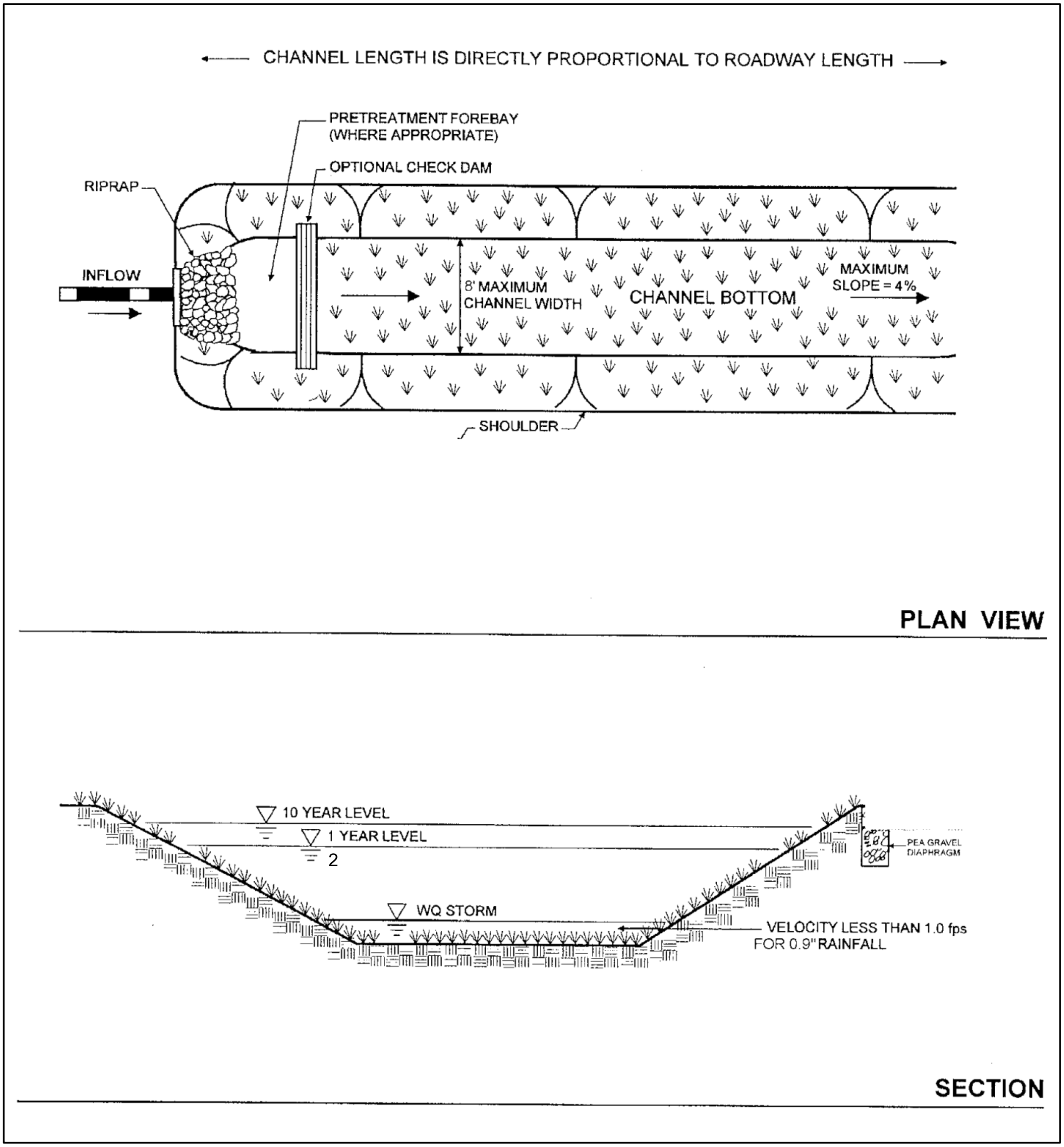

Figure 7A.2. Grass Channel – Typical Plan, Profile and Section
(Source: VADCR, 2011, MWS edited 2020)

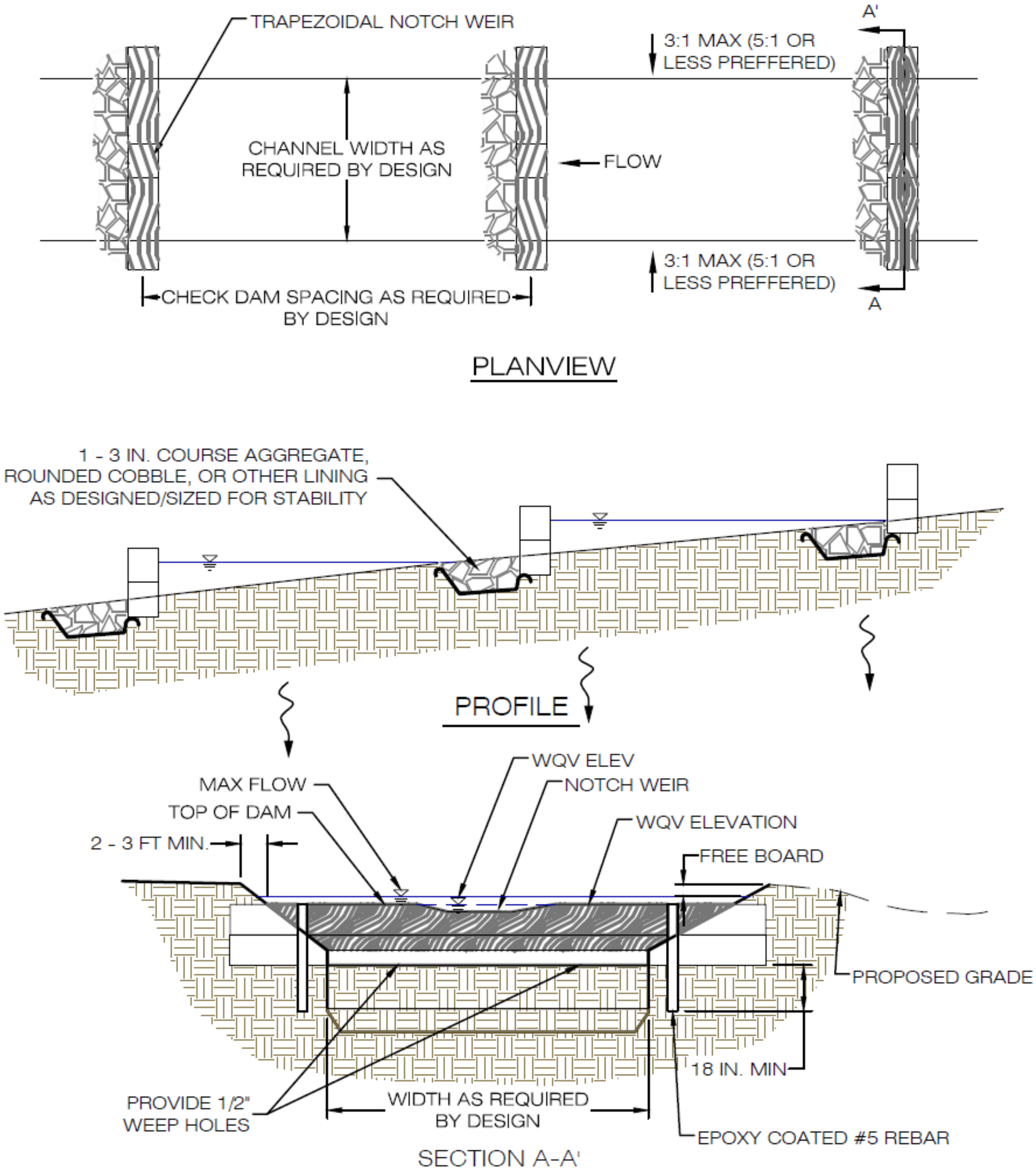

Figure 7A.3 Grass Channel with Check Dams – Typical Plan, Profile, and Section

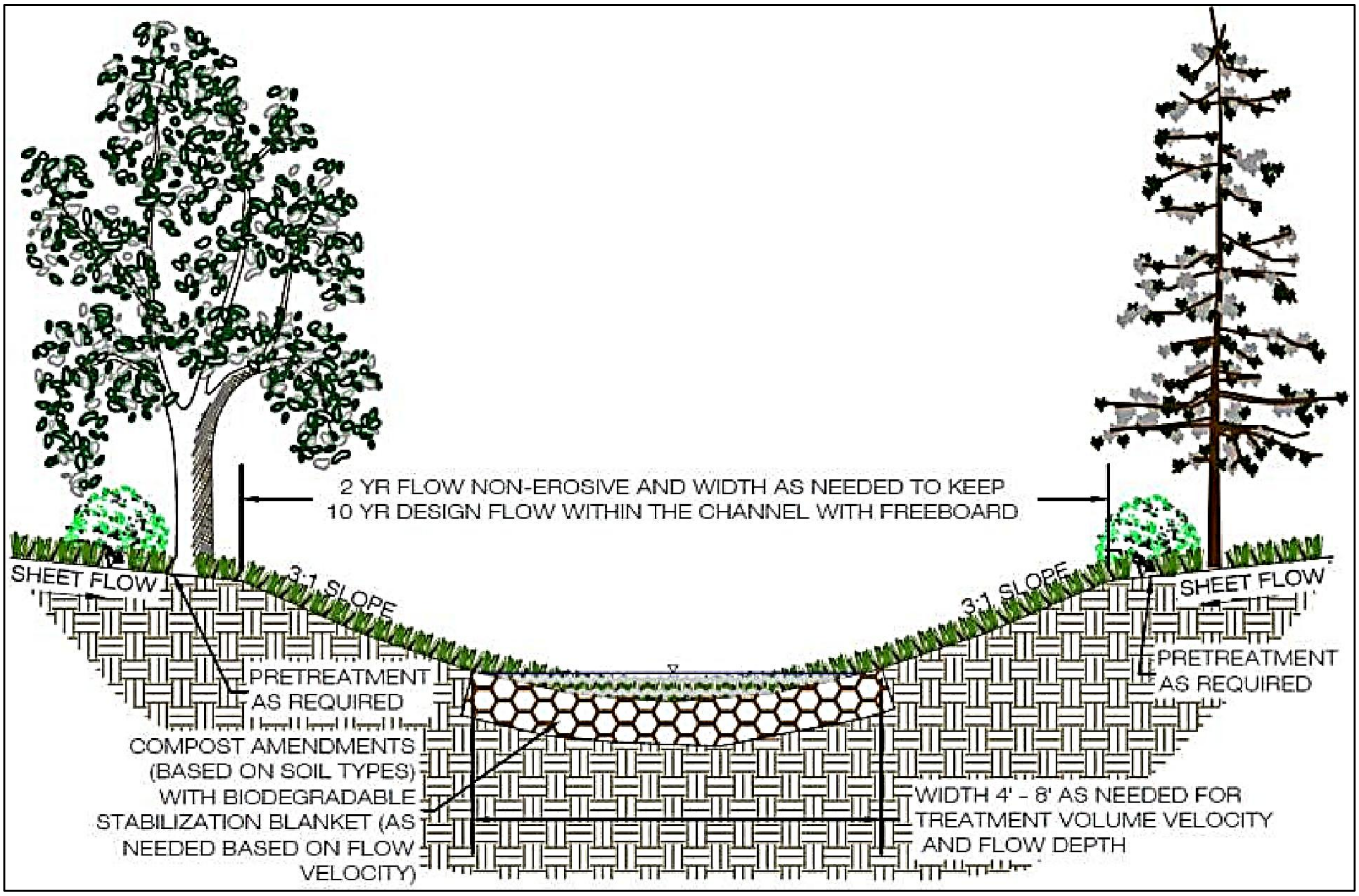

Figure 7A.4: Grass Channel with Compost Amendments - Section

APPENDIX 7-C
AS-BUILT REQUIREMENTS

A printer friendly version of this table can be found on the MWS Development Services website or by request.

Grass Channel Number:

	Design	As-built
Top of Bank Elevation		
Channel Slope		
Invert Elevation (Upstream)		
Check Dam Height, FT		
Channel Drop, FT		
Invert Elevation (Downstream)		
Check dam spacing, FT		
Bottom width, FT		
ALL Elevation shall be NAVD88		

Compost Amendment Requirements (Please check one):
_____ 0” Compost Incorporated _____ 6” Compost Incorporated @ 12” Depth _____ 12” Compost Incorporated @ 24” Depth

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Sheet Flow

Description: Impervious areas are disconnected and runoff is routed over a level spreader to sheet flow over adjacent vegetated areas. This slows runoff velocities, promotes infiltration, and allows sediment and attached pollutants to settle and/or be filtered by the vegetation.

Advantages/Benefits:

- Cost effective
- Wildlife habitat potential
- High community acceptance

Disadvantages/Limitations:

- Small drainage area
- Sheet flow must be maintained to achieve design goals
- Often requires additional SCMs to achieve runoff reduction goals

Selection Criteria:

50%-75% Runoff Reduction Credits
See Table 8.1

Land Use Considerations:

- [x] **Residential**
- [x] **Commercial**
- [x] **Industrial**

Maintenance:

- Maintain dense, healthy vegetation to ensure sheet flow
- Inspect regularly for signs of erosion

M **Maintenance Burden**
L = Low M = Moderate H = High

SECTION 1: DESCRIPTION

The two design variants that treat sheet flow runoff are (1) *Conserved Open Space* and (2) designed *Vegetated Filter Strips*. They act by slowing the runoff velocity and forcing the contaminants to separate from the runoff by means of settling or filtration. The design, installation, and management of these two design variants are quite different, as outlined in this specification. In both instances, storm water runoff must enter the conserved open space or vegetated filter strip as sheet flow. If the inflow is from a pipe or channel, an engineered level spreader must be designed in accordance with the criteria contained herein to convert the concentrated flow to sheet flow.

SECTION 2: PERFORMANCE

With proper design and maintenance, these practices can provide relatively high runoff reduction as shown in **Table 8.1**.

Table 8.1: Runoff Volume Reduction Provided by Filter Strips

Stormwater Function	Conservation Area		Vegetated Filter Strip[1]
	HSG Soils A and B	HSG Soils C and D	HSG Soils A, B, C, D
Runoff Vol. Reduction (RR)	75%	50%	50%

[1] Compost amended soils required for B, C, & D (see **Appendix 8-B**)

SECTION 3: SCHEMATICS

See Appendix 8-A for schematics for use in sheet flow treatment design.

SECTION 4: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Conserved open space or vegetated filter strips can be implemented on development sites where development density, topography and soils are suitable. Key considerations for conserved open space or vegetated filter strips include:

Soils. Conserved open space and vegetated filter strips are appropriate for all soil types, except fill soils.

Available Space. The conserved open space must be fully protected during the construction stage of development and kept outside the limits of disturbance.

Utilities. Public underground utilities and associated easements shall not be located within the conserved open space. Underground utilities that cross vegetated filter strips are acceptable.

Contributing Drainage Area. Designers may apply a runoff reduction credit to any impervious area that is hydrologically connected and effectively treated by a protected conserved open space and vegetated filter strip. Vegetated filter strips are used to treat very small drainage areas containing 5,000 square feet of impervious area or less.

Hotspot Land Uses. Conserved open space or vegetated filter strips should not receive hotspot runoff, since the infiltrated runoff could cause groundwater contamination.

Applications. Areas adjacent to water quality buffers or within forests or floodplains are well suited for conserved open space. Vegetated Filter Strips are best suited to treat runoff from small segments of impervious cover (usually less than 5,000 sq. ft) adjacent to road shoulders, small parking lots and rooftops. Vegetated Filter Strips may also be used as pretreatment for another stormwater practice such as a dry swale, bioretention, or infiltration areas. If sufficient pervious area is available at the site, larger areas of impervious cover can be treated by vegetated filter strips, using an engineered level spreader to recreate sheet flow.

SECTION 5. DESIGN CRITERIA

5.1 Stormwater Quality

Conserved open space and vegetated filter strips must meet the appropriate minimum criteria outlined in **Table 8.2** to qualify for the indicated level of runoff reduction. In addition, designers must conduct a site reconnaissance prior to design to confirm topography and soil conditions.

Table 8.2. Sheet Flow Design Criteria		
Design Issue	**Conserved Open Space**	**Vegetated Filter Strip**
Soil and Vegetative Cover	Undisturbed soils and native vegetation	Amended soils and dense turf cover or landscaped with herbaceous cover, shrubs, and trees
Overall Slope and Length (parallel to flow)	0.5% to 3% Slope – Minimum 35 ft length 3% to 6% Slope – Minimum 50 ft length The first 10 ft. of filter must be 2% or less in all cases	1% to 4% Slope – Minimum 35 ft. length 4% to 6% Slope – Minimum 50 ft. length 6% to 8% Slope – Minimum 65 ft. length The first 10 ft. of filter must be 2% or less in all cases
Width (perpendicular to flow)	Equal to the width of the contributing drainage area (CDA). Pretreatment is required.	

5.2 Pretreatment

Gravel Diaphragms: A gravel diaphragm at the top of the slope is required for both Conserved Open Space and Vegetated Filter Strips that receive sheet flow equal to the CDA width. Refer to **Figure 8.2** in **Appendix 8-A.**

- The flow should travel over the impervious area and to the practice as sheet flow and then drop at least 2 to 3 inches onto the gravel diaphragm.
- A layer of filter fabric shall be placed between the gravel and the underlying soil trench (ASTM D4632, ASTM D3786, ASTM D4491, and ASTM D4751).
- The gravel diaphragm is created by excavating a 2-foot wide and 1-foot deep trench that runs on the same contour at the top of the filter strip.
- Gravel shall consist of clean washed #57 stone meeting TDOT construction specifications.

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. The permeable berm should have the following properties:

- The berm 6 to 12 inches high.
- A permeable berm is not needed when vegetated filter strips are used as pretreatment to another stormwater practice.
- Permeable berm shall consist of TDOT machined rip-rap class A-3.

Engineered Level Spreaders (ELS). The design of engineered level spreaders ensure non-erosive sheet flow into the vegetated area. Section 7.26 of the TDEC Erosion and Sediment Control Handbook or TDOT specification EC-STR-61 shall be used for ELS design and material specifications. The maximum flow permitted through the ELS is 30 cfs for the 10-year storm event.

5.3 Planting and Vegetation Management

Conserved Open Space. No grading or clearing of native vegetation is allowed within Conserved Open Space. A long-term vegetation management plan must be prepared and the area must be protected by a perpetual easement or deep restriction. See **Section 8.1** for additional information.

Vegetated Filter Strips. 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. If used in conjunction with Reforestation reference GIP-10 for planting requirements.

SECTION 6: CONSTRUCTION

6.1 Construction Erosion Prevention and Sediment Control

Construction Stage EPSC Controls. Sheet Flow areas should be fully protected by EPSC measures as specified in the plans. These areas should remain outside the limits of disturbance during construction to prevent soil compaction by heavy equipment. In addition, the Sheet Flow areas shall be clearly identified on all construction drawings and EPSC plans during construction.

6.2 Construction Sequence

The following is a typical construction sequence for a Sheet Flow area, although steps may be modified to reflect different site conditions.

Step 1. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area to ensure they conform to original design. 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 2. Sheet Flow area construction may only begin after the entire contributing drainage area has been stabilized with vegetation. Any accumulation of sediments that does occur within the Sheet Flow area must be removed during the final stages of grading. EPSC for construction of the Sheet Flow area should be installed as specified in the erosion and sediment control plan.

Step 3 (Optional). Incorporate compost amendments according to Appendix 8-B.

Step 4. Install pretreatment measure(s).

Step 5. Install plantings and ground cover per approved plan. The construction contract should contain a care and replacement warranty extending at least two growing seasons, to ensure adequate growth and survival of the plant community.

Step 6. Conduct the final construction inspection and develop a punch list for facility acceptance. Then log the GPS coordinates for Sheet Flow and submit them to MWS.

SECTION 7. AS-BUILT REQUIREMENTS

After the Sheet Flow area has been constructed, the owner/developer must have an as-built certification conducted by a registered Professional Engineer. The as-built certification verifies that the GIP was installed per the approved plan. Supporting documents such as invoices and compost certification shall be provided in addition to the as-built requirements found in SWMM Volume 1.

SECTION 8. MAINTENANCE

8.1 Maintenance Document

The Sheet Flow GIP must be covered by a drainage easement to allow inspection and maintenance and be included in the site's Maintenance Document. If the filter area is a natural Conserved Open Space, 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.

The requirements for the Maintenance Document are in Appendix C of Volume 1 of the Manual. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long-Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities. The property owner must submit annual inspection and maintenance reports to MWS.

A long-term vegetation management plan must be prepared to maintain the Conserved Open Space in a natural vegetative condition. Generally, Conserved Open Space management plans do not 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.

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.

Inspectors should check to ensure that:

- Flows through the Filter Strip do not short-circuit the overflow control section;
- Debris and sediment does not build 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.

8.3 Ongoing Maintenance

Once established, Vegetated Filter Strips have minimal maintenance needs outside of the spring clean-up, regular mowing, repair of check dams and other measures to maintain the hydraulic efficiency of the strip and a dense, healthy grass cover. Vegetated Filter Strips that consist of grass/turf cover should be mowed at least twice a year to prevent woody growth.

SECTION 9. REFERENCES

Cappiella, K., T. Schueler, and T. Wright. 2006. *Urban Watershed Forestry Manual, Part 2. Conserving and Planting Trees at Development Sites*. Center for Watershed Protection. Prepared for United States Department of Agriculture, Forest Service.

Chesapeake Stormwater Network (CSN). 2008. *Technical Bulletin 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed.* Version 1.0. Baltimore, MD.

City of Portland, Environmental Services. 2004. *Portland Stormwater Management Manual*. Portland, OR. Available online at: http://www.portlandonline.com/bes/index.cfm?c=dfbbh

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Ellicott City, MD.

CWP. 2007. *National Pollutant Removal Performance Database Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Hathaway, J. and B. Hunt. 2006. *Level Spreaders: Overview, Design, and Maintenance*. Department of Biological and Agricultural Engineering. NC State University. Raleigh, NC. http://www.bae.ncsu.edu/stormwater/PublicationFiles/LevelSpreaders2006.pdf.

Henrico County, Virginia. *Henrico County Environmental Program Manual*. Available online at: http://www.co.henrico.va.us/works/eesd/

Lantin, A. and M. Barrett. 2005. Design and Pollutant Reduction of Vegetated Strips and Swales. In: World Water Congress 2005, May 15, 2005, Anchorage, Alaska.

North Carolina State University. *Level Spreader Design Worksheet*. Available online at: http://www.bae.ncsu.edu/conted/main/handouts/lsworksheet.pdf

North Carolina Department of Environment and Natural Resources, Division of Water Quality. "Level Spreader Design Guidelines." January 2007. Available online at: http://h2o.enr.state.nc.us/su/ManualsFactsheets.htm

Northern Virginia Regional Commission. 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook.* Fairfax, Virginia.

Philadelphia Stormwater Management Guidance Manual. Available online at: http://www.phillyriverinfo.org/Programs/SubprogramMain.aspx?Id=StormwaterManual

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

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Virginia Department of Conservation and Recreation (VADCR). 1999. *Virginia Stormwater Management Handbook. Volumes 1 and 2*. Division of Soil and Water Conservation. Richmond, VA.

Virginia (VA). 2013. Stormwater Design Specification No. 2: Sheet Flow To a Vegetated Filter Strip or Conserved Open Space, version 2.0.

Virginia Department of Conservation and Recreation (VADCR). 2011. Stormwater Design Specification No. 2: Sheet Flow To a Vegetated Filter Strip or Conserved Open Space, version 1.9.

APPENDIX 8-A
SCHEMATICS

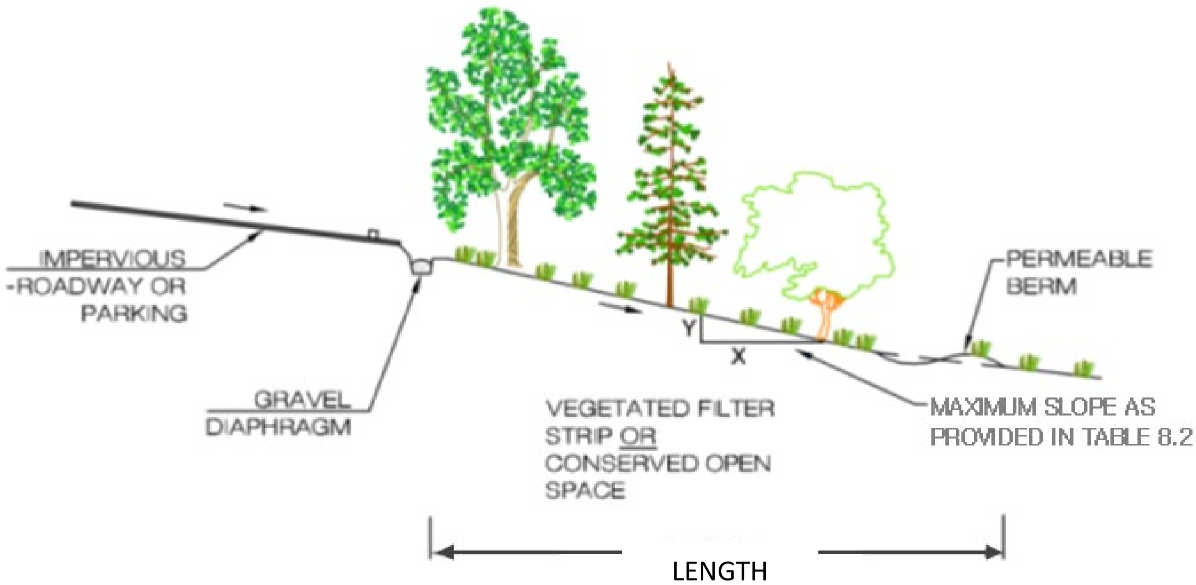

Figure 8.1. Typical Configuration of Sheet Flow to Filter Strip or Conserved Open Space (Source: VA, 2013; MWS edited 2020)

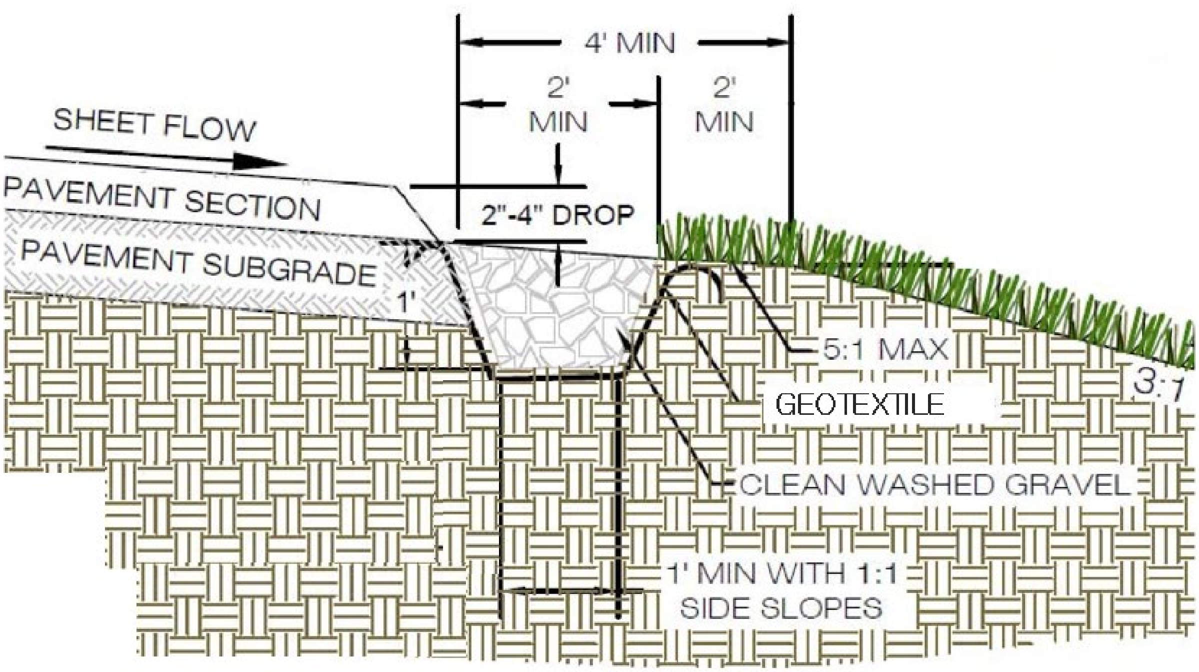

Figure 8.2 – Gravel Diaphragm – Sheet Flow Pretreatment (source: VADCR, 2011; MWS edited 2020)

APPENDIX 8-B
DESIGN CRITERIA FOR AMENDING SOILS WITH COMPOST

SECTION 1: DESCRIPTION

Soil restoration is a practice 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 runoff reduction performance.

SECTION 2: DESIGN CRITERIA

2.1 Determining Depth of Compost Incorporation

Table 8-B.1 presents some general guidance for compost amendments and incorporation depths.

Table 8-B.1. Compost and Incorporation Depths	
Compost (in)	12
Incorporation Depth (in)	24
Incorporation Method	Subsoiler

Once the area and depth of the compost amendments are known, the designer can estimate the total amount of compost needed using the following estimator equation:

Equation 8.1. Compost Quantity Estimation

$$C = A * D * 0.0031$$

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

2.2 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.ft.

APPENDIX 8-C
STANDARD NOTES

Required Bioretention Notes:

- Contractor, Engineer, or Owners Representative shall notify MWS NPDES Staff at least 48 hours prior to the installation of the compost amendments. Compost amendments must meet the requirements of GIP-08, Sheet Flow. Invoices or receipts for the compost amendments should be retained and submitted as part of the as-built.

APPENDIX 8-D
MISCELLANEOUS PHOTOS

Filter strip surrounding bioretention cell, Fort Bragg, NC.
(Source: N. Weinstein, LIDC)

Reforestation

Description: Reforestation refers to trees planted in groups in urban areas such as: parks, schools, public lands, vacant land, and neighborhood open spaces, to provide shade and stormwater retention and to add aesthetic value.

Advantages/Benefits:

- Reduces effective impervious cover
- Reduces stormwater runoff
- Provides aesthetic value
- Provides rainfall interception
- Shade provides cooling and energy savings
- Provides habitat
- Provides pollutant removal
- Provides flow attenuation

Disadvantages/Limitations:

- Poor quality urban soils may require soil amendments or remediation
- Long-term maintenance is required for high tree survival rates
- Must be implemented over large areas to see significant reduction in stormwater runoff
- Time required for trees to mature
- Poor soils, improper planting methods, conflicts with paved areas and utilities, inputs from road salt, lack of water, or disease can lead to low survival rate

Selection Criteria:

Twice the forest Rv factor for the corresponding soil type.

Equal to the forest Rv factor if amended soils are used in conjunction with reforestation.

***This GIP is subject to MWS approval**

Land Use Considerations:

- [x] **Residential**
- [x] **Commercial**
- [x] **Industrial**

Maintenance:

- Trees may require irrigation in dry periods

Maintenance Burden: L

L = Low M = Moderate H = High

SECTION 1: DESCRIPTION

Trees are often one of the most economical stormwater control measures. Trees also reduce the urban heat island effect, improve the urban aesthetic and improve air quality. Site reforestation involves planting trees at a development site with the explicit goal of establishing a mature forest canopy that will intercept rainfall, increase evapotranspiration rates, and enhance soil infiltration rates. Data and modeling show that urban trees can remove over 50% of the moisture in the soil beneath their canopy.

SECTION 2: PERFORMANCE

The overall runoff reduction credits for reforestation through lower runoff coefficients are summarized in **Table 9.1**.

Table 9.1. Runoff Volume Reduction Provided by Reforestation								
	Level 1 Design				**Level 2 Design**			
Hydrologic Soil Group	A	B	C	D	A	B	C	D
Runoff Volume Reduction (RR)	96%	94%	92%	90%	98%	97%	96%	95%
Impervious area may be routed to the reforestation area following the guidance and applying the Runoff Coefficient Credits detailed in GIP-09. The reforestation area should be treated as a vegetated filter strip for the application of this GIP.								

SECTION 3: PHYSCIAL FEASIBILITY & DESIGN APPLICATIONS

Reforestation can be implemented on development sites where development density, topography and soils are suitable. Key considerations for reforestation include:

Soils. Reforestation can be used on most soils. Mulch can be used around trees as an added filtration mechanism. The use of amended soils results in additional credit. Soils and mulch play a significant role in pollutant removal and tree health. Selection of soils and mulch intended to improve stormwater controls should allow water to infiltrate into the soil, with planting soil characteristics and volume tailored to meet the needs of a healthy tree.

Available Space. The minimum contiguous area of reforestation must be greater than 5,000 square feet. The reforestation area must be protected by a perpetual stormwater easement or deed restriction which stipulates that no future development or disturbance may occur within the area.

Utilities. Designers must ensure that future tree canopy growth in the reforestation area will not interfere with existing overhead public utility lines. Public underground utilities and associated easements shall not be located within the reforestation footprint. Local utility design guidance shall be consulted in order to determine clearances required between stormwater infrastructure and other dry and wet utility lines. Private utilities should not be located within the reforestation area when possible.

Applications. Reforestation refers to trees planted in groups in urban areas such as: parks, schools, public lands, vacant land, and neighborhood open spaces, to provide shade and stormwater retention and to add aesthetic value. Vegetation management plans must account for Health Department codes regarding overgrown lots and safety concerns of the residents.

SECTION 4: DESIGN CRITERIA

4.1 Stormwater Quality

Level 1 Reforestation involves using soil types currently on a site, without soil amendments. Level 2 Reforestation requires the use of amended soils. Soil Amendment guidance is located in **Appendix 9-A**. Trees should be planted following tree selection criteria in **Table 9.2**.

Table 9.2. Design Specifications for Reforestation	
Item	**Specifications for Level 1 and Level 2**
Area	Minimum contiguous area of 5,000 sq. ft.

Tree Type	• No more than 20% of any single tree species.
	• 2/3 of trees must be large canopy.
	• Native species to be utilized. See the following resources for additional guidance:
	  o GIP-01 Appendix 1-D
	  o http://landfire.cr.usgs.gov/viewer/
	  o http://www.se-eppc.org/pubs/middle.pdf

Density	• 300 large canopy trees – species that normally achieve an overall height at maturity of thirty feet or more per acre • 10 shrubs substitute for 1 large canopy tree • 2 small canopy trees substitute for 1 large canopy tree
Canopy Rate	Achieve 75% forest canopy within first 10 years
Size	Tree - Minimum tree size 6-8 ft in height Shrub – 18-24 inches or 3-gallon size
Ground Cover	Entire area should be covered with 2-4 inches of organic mulch or a native seed mix

4.2 Reforestation Planting Plan

A landscaping plan must be provided for the reforestation area. Minimum plan elements shall include the proposed planting plan for the reforestation area, the list of planting stock, sources of plant species, sizes of plants, and the planting sequence along with post-nursery care and initial maintenance requirements.

The planting plan must be prepared by a qualified Landscape Architect. The Landscape Architect shall certify the planting plan with certification statement, located on the reforestation planting plan. Standard certification statement can be found in **Appendix 9-B**.

SECTION 5: CONSTRUCTION

5.1 Construction Erosion Prevention and Sediment Control

Construction Stage EPSC Controls. Reforestation areas should be fully protected by EPSC measures as specified in the plans. These areas should remain outside the limits of disturbance during construction to prevent soil compaction by heavy equipment. In addition, the reforestation area shall be clearly identified on all construction drawings and EPSC plans during construction.

5.2 Construction Sequence

The following is a typical construction sequence for a reforestation area, although steps may be modified to reflect different site conditions.

Step 1. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area to ensure they conform to original design. 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 2. Reforestation may only begin after the entire contributing drainage area has been stabilized with vegetation. Any accumulation of sediments that does occur within the reforestation area must be removed during the final stages of grading. EPSC for construction of the reforestation area should be installed as specified in the erosion and sediment control plan.

Step 3 (Optional). Incorporate compost amendments according to **Appendix 9-A**.

Step 4. Install plantings and ground cover per approved plan. The construction contract should contain a care and replacement warranty extending at least two growing seasons, to ensure adequate growth and survival of the plant community.

Step 5. Conduct the final construction inspection and develop a punch list for facility acceptance. Then log the GPS coordinates for reforestation area and submit them to MWS.

SECTION 6: AS-BUILT REQUIREMENTS

After the reforested area has been constructed, the owner/developer must have an as-built certification conducted by a registered Professional Engineer. The as-built certification verifies that the GIP was installed per the approved plan. The following items shall be provided in addition to the as-built requirements found in SWMM Volume 1.

1. Landscape Architect letter certifying that the SCM plantings have been installed in general conformance with the approved plans and, with proper maintenance, should achieve 75% canopy coverage within the first ten years.
2. Supporting documents such as invoices and compost certification.

SECTION 7: MAINTENANCE

The requirements for the Maintenance Document are in Appendix C of Volume 1 of the Manual. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long-Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities. The property owner must submit annual inspection and maintenance reports to MWS.

Mowing is permitted but not encouraged between the trees while they are being established. Eventually, the canopy should shade out the grass and forest undergrowth will be established removing the need to mow. Vegetation management plans should consider if residents would prefer the site mowed in perpetuity.

Additional maintenance activities include:

- Watering the trees as needed during dry periods
- Repairing areas of erosion or reseeding areas that are bare
- Removing trash and debris from area
- Replanting any trees that die throughout the year. (The construction contract should contain a care and replacement warranty extending at least two growing seasons, to ensure adequate growth and survival of the plant community.)
- Addressing areas of standing water which might breed mosquitoes
- Picking up branches that have fallen
- Grooming trees or shrubs as needed
- Removing any trees or limbs damaged in storms that might pose a danger

SECTION 8: REFERENCES

Balousek. 2003. Quantifying decreases in stormwater runoff from deep-tilling, chisel-planting and compost amendments. Dane County Land Conservation Department. Madison, Wisconsin.

Chollak, T. and P. Rosenfeld. 1998. Guidelines for Landscaping with Compost-Amended Soils. City of Redmond Public Works. Redmond, WA. Available online at: http://www.ci.redmond.wa.us/insidecityhall/publicworks/environment/pdfs/compostamendedsoils.pdf.

City of Chesapeake. 2010. Chesapeake Landscape Specifications Manual: Tree and Shrub Planting Guidelines. Approved on October 16, 2008 and amended effective August 1, 2010. Available online at: http://www.chesapeake.va.us/services/depart/planning/pdf/ord-Landscape-Specifications-Manual_adopted-0901608.pdf.

City of Portland. 2008. "Soil Specification for Vegetated Stormwater Facilities." Portland Stormwater Management Manual. Portland, Oregon.

Virginia Dept. of Conservation and Recreation. 2010. Design Specification No. 4: Soil Compost Amendment Version 1.7, Appendix 4-A, Initial Minimum Design Criteria for Reforestation, Disconnection, Filter Strips, and Grass Channels. Available online at: http://csnetwork.squarespace.com/all-things-stormwater/soil-compost-amendments.html.

Figure 9.1 MWS Tree Planting Event

APPENDIX 9-A
DESIGN CRITERIA FOR AMENDING SOILS WITH COMPOST

SECTION 1: DESCRIPTION

Soil restoration is a practice 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 runoff reduction performance.

SECTION 2: DESIGN CRITERIA

2.1 Determining Depth of Compost Incorporation

Table 9-A.1 presents some general guidance for compost amendments and incorporation depths.

Table 9-A.1. Compost and Incorporation Depths

	Level 2
Compost (in)	12
Incorporation Depth (in)	24
Incorporation Method	Subsoiler

Once the area and depth of the compost amendments are known, the designer can estimate the total amount of compost needed using the following estimator equation:

Equation 7.1. Compost Quantity Estimation

$$C = A * D * 0.0031$$

Where: C = compost needed (cu. yds.)

A = area of soil amended (sq. ft.)

D = depth of compost added (in.)

2.2 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.ft.

APPENDIX 9-B
STANDARD NOTES

Required Reforestation Note:

- I hereby certify that this reforestation planting plan is in keeping with the requirements listed in GIP-9 Section 4. Only native species and/or non-invasive species of plants were used in the design of this reforestation planting plan. This plan will achieve at least 75% canopy coverage within the first ten years, and has the minimum amount of required trees.

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Cisterns

Description: Cisterns are used to intercept, divert, store and release rain falling on rooftops for future use.

Advantages/Benefits:

- Water source for non-potable uses (toilet flushing, irrigation)

Disadvantages/Limitations:

- Systems must drain between storm events
- Underground storage tanks must be designed to support anticipated loads
- Certain roof materials may leach metals or hydrocarbons, limiting potential uses for harvested rainwater

Selection Criteria:
Up to 90% Runoff Reduction Credit

Land Use Considerations:

- [X] **Residential**
- [X] **Commercial**
- [X] **Industrial**

Maintenance:

- Gutters and downspouts should be kept clean and free of debris and rust.
- Annual inspection

[H] **Maintenance Burden**
L = Low M = Moderate H = High

SECTION 1: DESCRIPTION

A cistern intercepts, diverts, stores and releases rainfall for future use. The term cistern is used in this specification, but it is also known as a rainwater harvesting system. 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 reuse. The actual runoff reduction rates for rainwater harvesting systems are "user defined," based on tank size, configuration, demand drawdown, and use of secondary practices.

There are six primary components of a rainwater harvesting system:

- Roof surface
- Collection and conveyance system (e.g. gutter and downspouts)
- Pre-screening and first flush diverter
- Storage tank
- Distribution system
- Overflow, filter path or secondary runoff reduction practice

SECTION 2: PERFORMANCE

The overall stormwater functions of the rainwater harvesting systems are described in **Table 10.1.**

Table 10.1: Runoff Volume Reduction Provided by Rainwater Harvesting	
Stormwater Function	**Performance**
Runoff Volume Reduction (RR)	Variable up to 90%[1]
Treatment Volume (Tv) Multiplier[2]	1.0

[1]Credit is variable. Credit up to 90% 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 event occurs. The total credit may not exceed 90%.
[2]Incorporated into LID Site Design Tool calculations

SECTION 3: SCHEMATICS

See Appendix 10-A for schematics for use in cistern design.

SECTION 4: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

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:

Soils. The bearing capacity of the soil upon which the cistern will be placed should be considered, as full cisterns can be very heavy. Storage tanks should only be placed on native soils or on fill in accordance with the manufacturer's guidelines, or in consultation with a geotechnical engineer.

Available Space. Adequate space is needed to house the 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 or within buildings that are structurally designed to support the added weight, and adjacent to buildings.

Elevation Considerations. Site topography and tank location should be considered as they relate to all of the inlet and outlet invert elevations in the rainwater harvesting system. Site topography and tank location will also affect the amount of pumping needed. In general, it is often best to locate the cistern close to the building, ensuring that minimum roof drain slopes and enclosure of roof drain pipes are sufficient.

Subsurface Constraints. The cistern itself must be located sufficiently below grade and below the frost line, resulting in an additional elevation drop. Cisterns should be separated from the water table to prevent risk of floatation. 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"), conducting buoyancy calculations when the tank is empty, etc. 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.

Utilities. Public underground utilities and associated easements shall not be located within the cistern footprint. Local utility design guidance shall be consulted in order to determine clearances required between stormwater infrastructure and other dry and wet utility lines.

Contributing Drainage Area. The contributing drainage area (CDA) to the cistern is the impervious area draining to the tank. In general, only rooftop surfaces should be included in the CDA. 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.

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.

Floodplains. Flood waters shall be prohibited from entering the cistern overflow system.

Applications. Cisterns are typically used in medium to high density commercial, institutional and residential sites to capture and reuse rainwater. 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.), supply for chilled water cooling towers, replenishing and operation of laundry, if approved by Metro Water Services (MWS).

SECTION 5: DESIGN CRITERIA

5.1 Sizing of Cisterns

5.1.1 Stormwater Quality

To determine runoff volume reduction, MWS utilizes the Rainwater Harvester 2.0. The model, user manual and local data can be found at http://www.nashville.gov/stormwater.

5.2 Pretreatment

Pretreatment methods should be implemented per manufacturers specifications. Pretreatment is required to keep sediment, leaves, contaminants and other debris from the system. Leaf screens and gutter guards are recommended to capture floatables before entering the system. Rooftop runoff should be filtered to remove sediment before it is stored.

5.3 Conveyance and Overflow

An overflow structure should always be incorporated into on-line designs to safely convey larger storms through the cistern. The system must be designed with an overflow mechanism to divert runoff when the storage tanks are full. Overflows should discharge to pervious areas set back from buildings and paved surfaces, or to secondary SCMs.

5.4 Design Guidance

Design guidance for rainwater harvesting systems are presented in **Table 10.2** Designers should consult with experienced cistern installers on the choice of recommended manufacturers of prefabricated tanks and other system components.

Table 10.2. Design Guidance for Rainwater harvesting systems	
Item	**Specification**
Gutters and Downspout	PVC 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.
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 watertight 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.
Distribution Systems	• Pump that produces sufficient pressure for all end-uses. • Separate plumbing labeled as non-potable may be required. • Backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.

Note: This table does not address indoor systems or pumps.

5.5 Cistern Materials

Rainwater harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. The material options for cisterns are presented in **Table 10.3**. Designers should consult manufacturer's technical specifications for specific criteria and guidance.

Table 10.3. Advantages and Disadvantages of Various Cistern Materials		
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

Table 10.3. Advantages and Disadvantages of Various Cistern Materials		
Tank Material	**Advantages**	**Disadvantages**
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

Source: Cabell Brand (2007, 2009)

SECTION 6: SPECIAL CASE DESIGN ADAPTATIONS

6.1 Steep Terrain

Rainwater harvesting systems can be useful in areas of steep terrain where other stormwater treatments are inappropriate, provided the systems are designed in a way that protects slope stability. Cisterns should be located in level areas where soils have been sufficiently compacted to bear the load of a full storage tank.

SECTION 7: CONSTRUCTION

7.1 Construction

Construction Stage Erosion and Sediment Controls. Stormwater Management Manual Volume 4 or TDEC EPSC Handbook should be utilized for proper EPSC controls during construction.

Excavation. The proposed site should be checked for existing utilities prior to any excavation. The excavated area should be prepared in accordance with the manufacturer's installation specifications.

7.2 Cistern Installation

The contractor should be familiar with cistern installation. 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.

Step 1. Choose the tank location on the site.

Step 2. Route all downspouts or roof drains to pre-screening devices and first flush diverters.

Step 3. Properly install the tank.

Step 4. Install the pump (if needed) and piping to end-uses (indoor, outdoor irrigation, or tank dewatering release.

Step 5. Route all pipes to the tank.

Step 6. Stormwater should not be diverted to the rainwater harvesting system until the overflow filter path has been stabilized with vegetation.

Step 7. Conduct the final construction inspection (see Section 8). Then log the GPS coordinates for each cistern and submit them to MWS.

SECTION 8: AS-BUILT REQUIREMENTS

After the cistern has been constructed, the owner/developer must have an as-built certification of the cistern conducted by a registered Professional Engineer. The as-built certification verifies that the GIP was installed per the approved plan. The following items shall be provided in addition to the as-built requirements found in SWMM Volume 1.

1. The Engineer shall include a copy of the GIP summary table found in Appendix 10-B.
2. Supporting documents such as invoices and photos shall be included in the submittal package.

SECTION 9: MAINTENANCE

9.1 Maintenance Document

The requirements for the Maintenance Document are in Appendix C of Volume 1 of the Manual. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long-Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities. The property owner must submit annual inspection and maintenance reports to MWS.

9.2 Maintenance Inspections

All rainwater harvesting systems components shall be inspected by the property owner twice per year (preferably Spring and the Fall). A comprehensive inspection by a professional engineer or landscape architect shall occur every five years. Maintenance checklists are located in Volume 1 Appendix C of this Manual.

9.3 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 10.4** describes routine maintenance tasks to keep rainwater harvesting systems in working condition.

Table 10.4. 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

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

Although rainwater harvesting is an ancient practice, it is enjoying a revival due to the inherent quality of rainwater and the many beneficial uses that it can provide (TWDB, 2005). Some common concerns associated with rainwater harvesting that must be addressed during design include:

Winter Operation. 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.

Plumbing Codes. Designer and plan reviewers shall consult building codes to determine if they explicitly allow the use of harvested rainwater for toilet and urinal flushing. In the cases where a Metro backup supply is used, rainwater harvesting systems are required to 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.

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.

Child Safety. Above-grade residential rainwater harvesting systems cannot have unsecured openings large enough for children to enter the tank. For underground cisterns, manhole access should be secured to prevent unwanted access.

SECTION 11: REFERENCES

Cabell Brand Center. 2009. *Virginia Rainwater Harvesting Manual, Version 2.0*. Salem, VA. (Draft Form) http://www.cabellbrandcenter.org

Cabell Brand Center. 2007. *Virginia Rainwater Harvesting Manual*. Salem, VA. http://www.cabellbrandcenter.org

Center for Watershed Protection (CWP). 2007. *Urban Stormwater Retrofit Practices.* Manual 3 in the Urban Subwatershed Restoration Manual Series. Ellicott City, MD.

City of Portland, Environmental Services. 2004. *Portland Stormwater Management Manual*. Portland, OR. http://www.portlandonline.com/bes/index.cfm?c=dfbcc

City of Tucson, AZ. 2005. *Water Harvesting Guidance Manual*. City of Tucson, AZ. Tucson, AZ.

Coombes, P. 2004. *Water Sensitive Design in the Sydney Region. Practice Note 4: Rainwater Tanks*. Published by the Water Sensitive Design in the Sydney Region Project. http://www.wsud.org/planning.htm

Credit Valley Conservation. 2008. *Credit River Stormwater Management Manual*. Mississauga, Ontario.

Forasté, J. Alex and Hirschman David. 2010. *A Methodology for using Rainwater Harvesting as a Stormwater Management BMP*. ASCE International Low Impact Development Conference, Redefining Water in the City. San Francisco, CA.

Gowland, D. and T. Younos. 2008. *Feasibility of Rainwater Harvesting BMP for Stormwater Management*. Virginia Water Resources Research Center. Special Report SR38-2008. Blacksburg, VA.

National Oceanic and Atmospheric Administration (NOAA). 2004. *NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 2, Version 3.0*. Revised 2006. Silver Spring, MD.

North Carolina Division of Water Quality. 2008. *Technical Guidance: Stormwater Treatment Credit for Rainwater Harvesting Systems*. Revised September 22, 2008. Raleigh, NC.

Northern Virginia Regional Commission. 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook*. Fairfax, Virginia.

Nova Scotia Environment. 2009. *The Drop on Water: Cisterns*. Nova Scotia.

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban stormwater retrofit practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

TWDB. 2005. *The Texas Manual on Rainwater Harvesting.* Texas: Texas Water Development Board.

Virginia (VA). 2013. Stormwater Design Specification No. 6: Rainwater Harvesting, Version 2.2.

Virginia Department of Conservation and Recreation (VADCR). 2011. Stormwater Design Specification No. 6: Rainwater Harvesting, Version 1.9.5, March 1, 2011.. Available at: http://vwrrc.vt.edu/swc/NonProprietaryBMPs.html.

APPENDIX 10-A
SCHEMATICS

Figure 10.1 through 10.3 provide typical schematics of cistern and piping system configurations

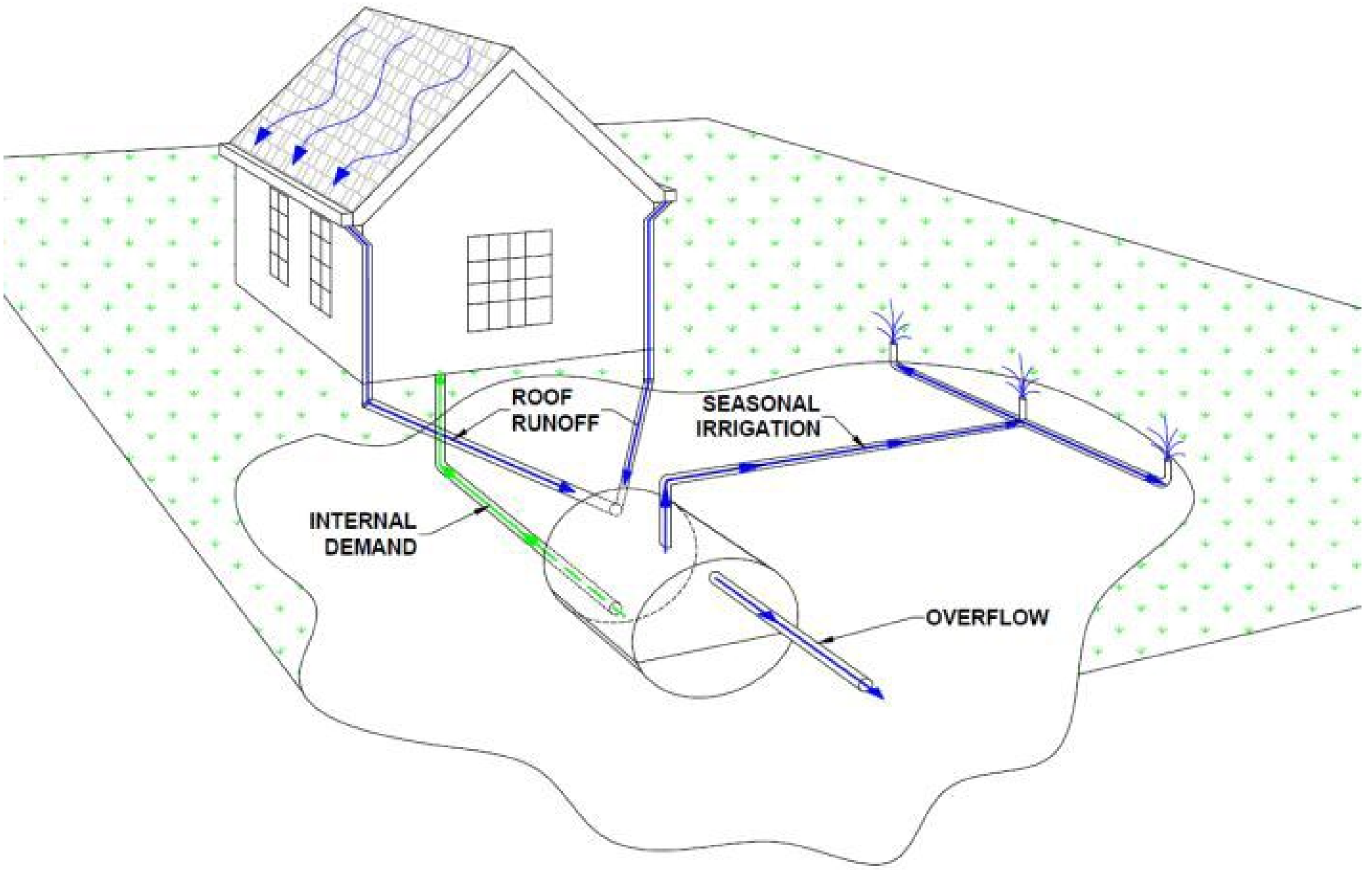

Figure 10.1. Configuration 1: Year-round indoor use with optional seasonal outdoor use (Source: VA, 2013)

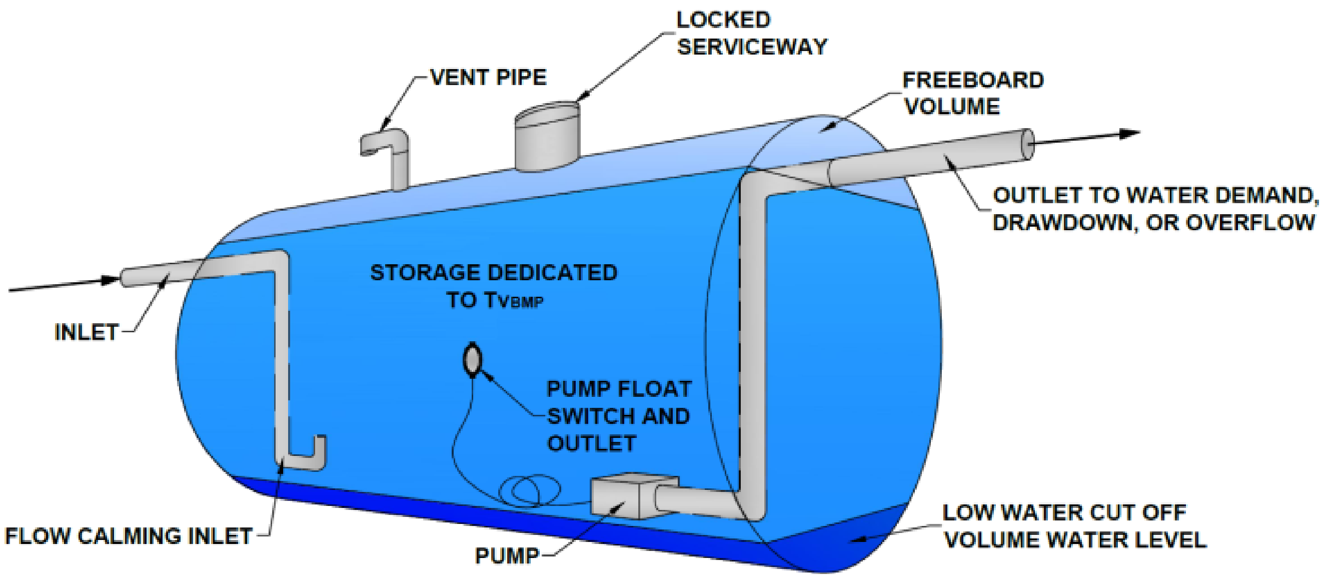

Figure 10.2. Tank Design 1: Storage Associated with Treatment Volume (Tv) only (Source: VA, 2013)

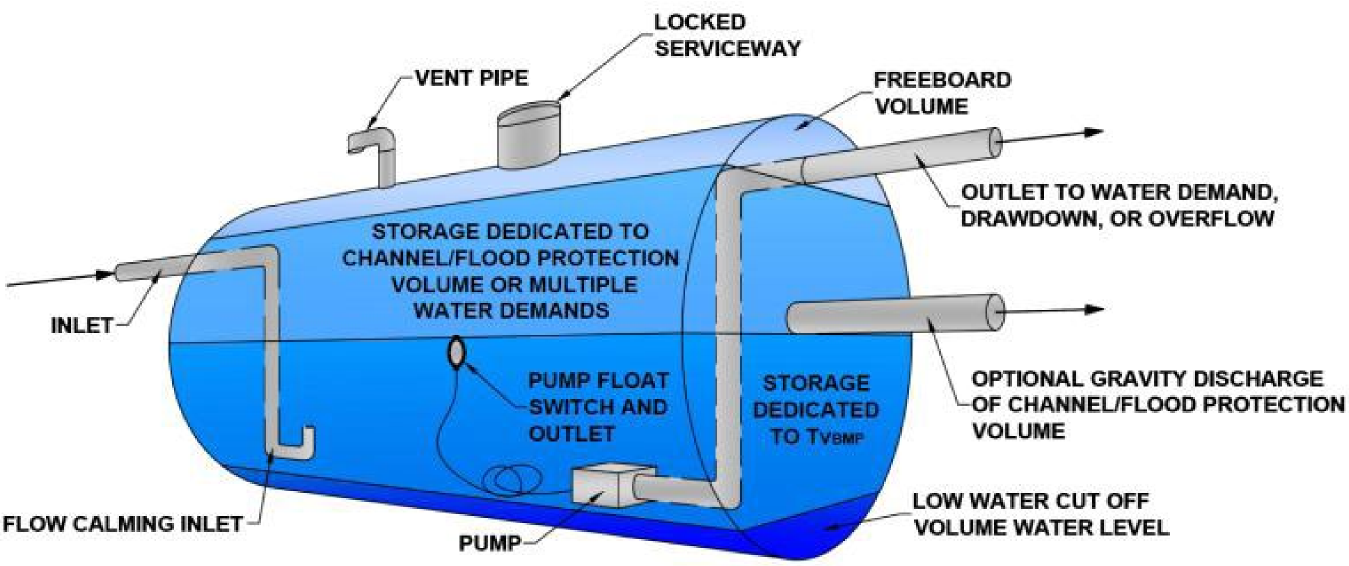

Figure 10.3. Tank Design 2: Storage Associated with Treatment, Channel Protection and Flood Volume (Source: VA, 2013)

APPENDIX 10-B
AS-BUILT REQUIREMENTS

A printer friendly version of this table can be found on the MWS Development Services website or by request.

Cistern Number:

	Design	As-built
Treatment Volume (Tv), CF		
Low Flow Orifice/ Weir*		
Overflow Invert		
* N/A if not required		
ALL Elevation shall be NAVD88		

APPENDIX 10-C
MISCELLANEOUS PHOTOS

The images below in **Figures 10.4 and 10.5** display three examples of various materials and shapes of cisterns discussed in **Table 10.3**.

Figure 10.4. Example of Multiple Fiberglass Cisterns in Series
(Source: VADCR, 2011)

Figure 10.5. Example of two Polyethylene Cisterns
(Source: VADCR, 2011)

Green Roof

Description: A green roof is a layer of vegetation installed on top of a conventional flat or slightly sloped roof that consists of waterproofing material, root permeable filter fabric, growing media, and specially selected plants.

Advantages/Benefits:

- Runoff volume reduction
- Provides flow attenuation
- Extends the life of a conventional roof by up to 20 yrs.
- Provides increased insulation and energy savings
- Reduces air pollution
- Provides habitat for wildlife
- Increases aesthetic value
- Reduces urban heat island effect

Disadvantages/Limitations:

- Cost may be greater than a conventional roof
- Feasibility may be limited by load-bearing capacity of roof
- Requires more maintenance than a conventional roof
- Plant survival and waterproofing are potential issues
- May require irrigation

Selection Criteria:

40% – 90% Runoff Reduction Credit

Land Use Considerations:

- [X] **Residential**
- [X] **Commercial**
- [X] **Industrial**

Maintenance:

- May include watering, fertilizing, and weeding, typically greatest in the first two years when plants are becoming established.
- Maintenance largely depends on the type of green roof system installed and the type of vegetation planted.

[M] **Maintenance Burden**
L = Low M = Moderate H = High

SECTION 1: DESCRIPTION

Green roofs (also known as *vegetated roofs, living roofs,* or *ecoroofs*) are alternative roof surfaces that typically consist of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth. Green roofs capture and temporarily store stormwater runoff in the growing media before it is conveyed into the storm drain system. A portion of the captured stormwater evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites.

There are two different types of green roof systems: intensive green roofs and extensive green roofs. Intensive systems have a deeper growing media layer, which is planted with a wider variety of plants, including shrubs and trees. By contrast, extensive systems typically have much shallower growing media (under 6 inches), which is planted with carefully selected drought tolerant vegetation such as sedums. Extensive green roofs are lighter and typically less expensive than intensive green roofs and are recommended for use on most development and redevelopment sites.

Green 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 towards the outlet. Green roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after vegetation is initially established. Tray systems are also available with removable dividers allowing the media to meld together creating a seamless appearance but with less difficulty in construction.

SECTION 2: PERFORMANCE

The overall stormwater functions of green roofs are summarized in **Table 11.1**.

Table 11.1: Runoff Volume Reduction Provided by Green Roofs				
Stormwater Function	**Level 1 Design**	**Level 2 Design**	**Level 3 Design**	**Level 4 Design**
Runoff Volume Reduction (RR)	40%	60%	80%	90%
Treatment Volume (Tv) Multiplier*	1.0	1.1	1.25	1.25

*Incorporated into LID spreadsheet calculations

SECTION 3: SCHEMATICS

See **Appendix 11-A** for schematics for use in green roof design.

SECTION 4: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Several site-specific features influence how green roofs 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 green roofs into the site design. The following are key considerations:

Available Space. A prime advantage of green roofs 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 prices are high.

Accessibility. Green roof facilities must be accessible to various types of equipment for periodic maintenance. The design may include non-vegetated walkways (e.g., permeable paver blocks) to allow for easy access to the roof for weeding and making spot repairs.

Contributing Drainage Area. Green roofs are intended to capture and treat only the precipitation that falls on their own footprint. Nominal areas of run-on may be permitted with MWS staff approval.

Structural Capacity of the Roof. A structural engineer, architect, or other qualified professional should be involved with all green roof designs to ensure that the building has enough structural capacity to support a green roof.

Roof Pitch. Treatment 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. Green roofs can be installed on rooftops with slopes up to 8%.

Building Codes. The green roof design should comply with the Metro Building Codes with respect to roof drains and emergency overflow devices. If the green roof is designed to be accessible, the access must not only be convenient for installation and maintenance purposes but also must adhere to Metro Building Codes and other regulations for access and safety.

Irrigation or Baseflow. The green roof shall not receive non-stormwater flows, except for irrigation as necessary during the first growing season for the survival of plantings.

Applications. Green 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. Designers may wish to pursue other design objectives for vegetated roofs, such as energy efficiency, green building or LEED points, architectural considerations, visual amenities and landscaping features, which are often maximized with intensive vegetated roof systems. However, these design objectives are beyond the scope of this specification.

SECTION 5: DESIGN CRITERIA

5.1 Sizing of Green Roof

5.1.1 Stormwater Quality

Green roof areas should be sized to capture the Treatment Volume (Tv). The required size of a green roof will depend on several factors, including the porosity and hydraulic conductivity of the growing media and the underlying drainage materials. Designers may choose between either a Level 1, Level 2, Level 3, or Level 4 design that maximizes nutrient and runoff reduction.

Sizing of the surface area (SA) for green roofs is based on the computed Treatment Volume (T_v) of the contributing drainage area and the storage provided in the facility. The required surface area (in square feet) is computed as the Treatment Volume (in cubic feet) divided by the equivalent storage depth (in feet). The equivalent storage depth is computed as the depth of media (in feet) multiplied by the accepted porosity. Based on volume calculations, the minimum reservoir layer is sufficient to contain the required Treatment Volume for the typical green roof area. **Table 11.2** lists the design criteria for Level 1, 2, 3, and 4 designs.

Table 11.2 Green Roof Typical Section

	Level 1 (inches)	Level 2 (inches)	Level 3 (inches)	Level 4 (inches)	Porosity Value (n)
Vegetative Surface	Varies based on design or manufacturer's specification*				N/A
Media	4	6	8	9	0.3**
Drainage Layers	Varies based on design or manufacturer's specification*				N/A

*Must be in conformance to ASTM E2777-20 Standard Guide for Vegetative (Green) Roof Systems.

**Site designers and planners should consult with green roof manufacturers and material suppliers for specific porosity.

5.2 Functional Elements of a Green Roof System

A green roof is composed of up to eight different systems or layers, from bottom to top, that are combined to protect the roof and maintain a vigorous cover. 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 roofing systems, whereas in other cases, the designer or architect must assemble their own system. Green roofs must be in conformance to ASTM E2777-20 Standard Guide for Vegetative (Green) Roof Systems.

5.3 Conveyance and Overflow

The drainage layer below the growth media should be designed to convey the 10-year storm without backing water up to into the growing media. The drainage layer should convey flow to an outlet or overflow system such as a traditional rooftop drainage system with inlets set slightly above the elevation of the green roof surface. 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.

5.4 Vegetation and Surface Cover

Plant selection for green rooftops 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, Sempervivum, or Hieracium* that is matched to the local climate conditions and can tolerate the difficult growing conditions found on building rooftops. Nashville lies in the transition zone between USDA Plant Hardiness Zones 6 and 7 (AHS, 2003).

Vegetation Considerations:

- 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.
- Designers should also match species to the expected rooting depth of the growing media, which can also provide enough lateral growth to stabilize the growing media surface.
- It is also important to note that many green roof plant species will *not* be native to the Southeast (which is in contrast to *native* plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
- When appropriate species are selected, most green roofs will not require supplemental irrigation, except during the first year that the green roof is being established and during periods of drought.
- 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.

A planting plan must be prepared for a green roof by a Landscape Architect or by meeting the manufacturer's specifications. If a Landscape Architect is used, they shall certify the planting plan with certification statement, located on the planting plan. Standard certification statement can be found in **Appendix 11-B**.

5.5 Material Specifications

The American Society for Testing and Materials (ASTM) recently updated the Standard Guide for Vegetative (Green) Roof Systems (ASTM E2777-20). Specification for green roof components are described and referenced in **Table 11.3**.

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 11.3. Green Roof Material Specifications	
Material	**Specification**
Roof	Structural Capacity should conform to ASTM E2397, *Practice for Determination of Live Loads and Dead Loads Associated with Green (Vegetated) Roof Systems*. In addition, use standard test methods ASTM E2398 for *Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems*, and ASTME 2399 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(Optional)	Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	1 to 2-inch layer of clean, washed granular material, such as ASTM D448 size No. 8 stone. Roof drains and emergency overflow should be designed in accordance with Metro 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	Media should consist primarily of lightweight mineral aggregates and have an organic matter content < 15%. The silt content shall not exceed 15%. Media should provide sufficient nutrients and water holding capacity to support the proposed plant materials. Maximum medium water retention shall fall between 30% to 45% based upon ASTM E2399.
Plant Materials	Low plants such as sedum, herbaceous plants, and perennial grasses that are shallow-rooted, self-sustaining, and tolerant of direct sunlight, drought, wind, and frost are best for intensive green roofs. Plant species should be based upon the type and depth of growth media. See ASTM E2400, *Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems*.

SECTION 6: CONSTRUCTION

6.1 Construction Sequence

The typical construction sequence for green roof system installation is provided below. This can be modified to reflect different green roof system applications or expected site conditions.

Step 1. Construct the roof deck with the appropriate slope and material.

Step 2. Install the waterproofing method, according to manufacturer's specifications.

Step 3. Conduct a flood test to ensure the system is watertight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system.

Step 4. Add additional system components (e.g., insulation, optional 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.

Step 5. 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.

Step 6. 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 installation and routinely during establishment.

Step 7. Conduct the final construction inspection (see **Section 9**). Then log the GPS coordinates for each green roof and submit them to MWS.

SECTION 7: AS-BUILT REQUIREMENTS

After the green roof has been constructed, the owner/developer must have an as-built certification of the green roof conducted by a registered Professional Engineer. The as-built certification verifies that the GIP was installed per the approved plan. The following items shall be provided in addition to the as-built requirements found in SWMM Volume 1.

1. Landscape Architect letter certifying that the SCM plantings have been installed in general conformance with the approved grading plans.
2. The Engineer shall include a copy of the GIP summary table found in **Appendix 11-C**.
3. Supporting documents such as invoices and photos shall be included in the submittal package.

SECTION 8: MAINTENANCE

8.1 Maintenance Inspections and Ongoing Operations

The requirements for the Maintenance Document are in Appendix C of Volume 1 of the Manual. They include the execution and recording of an Inspection and Maintenance Agreement or a Declaration of Restrictions and Covenants, and the development of a Long Term Maintenance Plan (LTMP) by the design engineer. The LTMP contains a description of the stormwater system components and information on the required inspection and maintenance activities. The property owner must submit annual inspection and maintenance reports to MWS.

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 11.4**). 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 (refer to ASTM E2400). Many practitioners also recommend an annual application of slow release fertilizer in the first few years after the vegetated roof is installed.

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.

Table 11.4. Typical Maintenance Activities Associated with Green Roofs	
Activity	**Schedule**
Water to promote plant growth and survival.	As needed
Inspect the vegetated roof and replace any dead or dying vegetation.	Following Construction
Inspect the waterproof membrane for leaking or cracks.	Semi-annually
Annual fertilization.	As needed
Weeding to remove invasive plants.	As needed
Inspect roof drains, scuppers and gutters to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris.	Semi-annually
Inspect the green roof for dead, dying or invasive vegetation. Plant replacement vegetation as needed.	As needed

SECTION 9: REFERENCES

American Horticultural Society (AHS). 2003. *United States Department of Agriculture Plant Hardiness Zone Map*. Alexandria, VA.

ASTM International. 2005. *Standard Test Method for Maximum Media Density for Dead Load Analysis of Green (Vegetated) Roof Systems*. Standard E2399-05. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/Standards/E2399.htm.

ASTM International. 2005. *Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green (Vegetated) Roof Systems*. Standard E2396- 05. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/ Standards/E2396.htm.

ASTM International. 2005. *Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems*. Standard E2398-05. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/ Standards/E2398.htm.

ASTM International. 2005. *Standard Practice for Determination of Dead Loads and Live Loads Associated with Green (Vegetated) Roof Systems*. Standard E2397-05. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/ Standards/E2397.htm.

ASTM International. 2006. *Standard Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems*. Standard E2400-06. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/Standards/E2400.htm.

ASTM International 2020. *Standard Guide for Vegetative (Green) Roof Systems.* Standard E2777-20. ASTM, International. West Conshohocken, PA. available online: https://www.astm.org/Standards/E2777.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.

Maryland Department of Environment. (MDE). 2008. *Chapter 5. Environmental Site Design.* "Green Roofs." Baltimore, MD.

Miller, C. 2008. *Green roofs as stormwater best management practices: Preliminary computation of runoff coefficients: sample analysis in the Mid-Atlantic states*. Roofscapes, Inc. Philadelphia, PA.

Moran, A., W. Hunt and G. Jennings. 2004. *Green roof research of stormwater runoff quantity and quality in North Carolina*. NWQEP Notes. No. 114. North Carolina State University. Raleigh, NC.

North Carolina State University (NCSU). 2008. *Green Roof Research Web Page*. Department of Biological and Agricultural Engineering. http://www.bae.ncsu.edu/greenroofs .

Northern Virginia Regional Commission (NVRC). 2007. *Low Impact Development Manual.* "Vegetated Roofs." Fairfax, VA.

Schueler et al 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

Snodgrass, E. and L. Snodgrass. 2006. *Green Roof Plants: a resource and planting guide*. Timber Press. Portland, OR.

Van Woert, N., D. Rowe, A. Andersen, C. Rugh, T. Fernandez and L. Xiao. 2005. "Green roof stormwater retention: effects of roof surface, slope, and media depth." *Journal of Environmental Quality*. 34: 1036-1044.

VADCR. 2011. Stormwater Design Specification No. 5: Vegetated Roof, Version 2.3, March 1, 2011. Virginia Department of Conservation and Recreation. http://vwrrc.vt.edu/swc/NonProprietaryBMPs.html.

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.

APPENDIX 11-A
SCHEMATICS

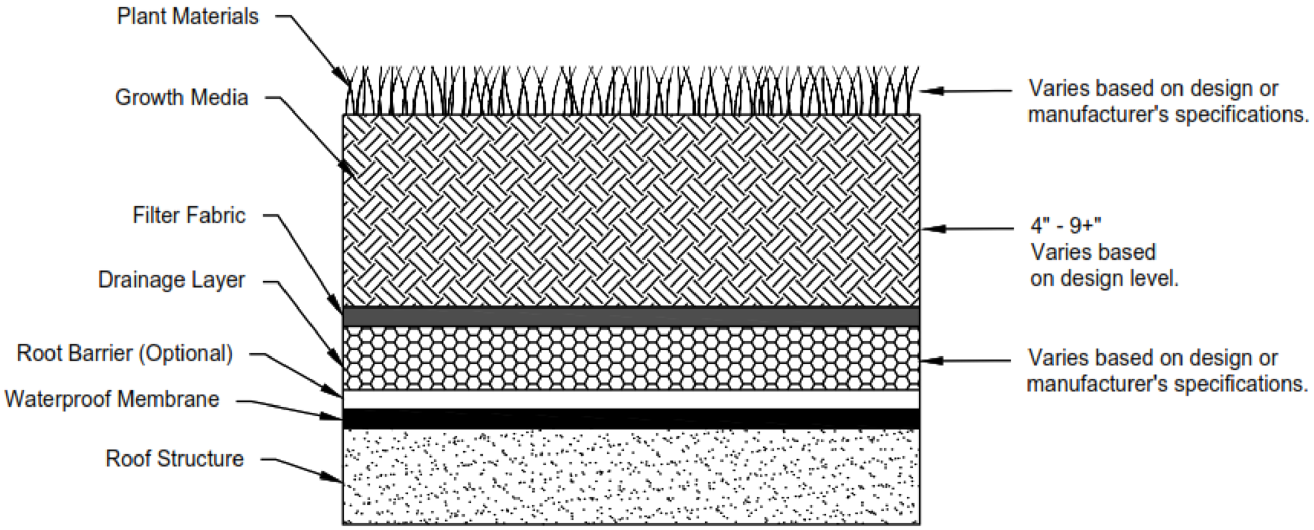

Figure 11.1. Typical Section – Intensive Vegetated Roof

APPENDIX 11-B
STANDARD NOTES

Required Green Roof Note:

- I hereby certify that this green roof planting is in keeping with the requirements listed in GIP-11. This green roof system is designed to establish a full and vigorous cover.

APPENDIX 11-C
AS-BUILT REQUIREMENTS

A printer friendly version of this table can be found on the MWS Development Services website or by request.

Green Roof Number:

	Design	As-Built
GIP Surface Area (SF)		
Media Depth (in)		

APPENDIX 11-D
MISCELLANEOUS PHOTOS

Figure 11.2. Photos of Vegetated Roof Cross-Sections (source: B. Hunt, NCSU)