Stormwater Management Guidebook

Prepared for:

District Department of the Environment

Watershed Protection Division

District of Columbia

Prepared by:

Center for Watershed Protection

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Preface

Technical information regarding future updates to the District of Columbia Stormwater Management Guidebook will be available at http://ddoe.dc.gov/publication/stormwater-guidebook. Notices regarding future versions of the manual will be posted on this website. Future versions are expected to occur, at most, once a year.

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Chapter 1 Introduction to the Stormwater Management Guidebook

1.1 Introduction

The District of Columbia (District), like most ultra-urban areas, experiences increased stormwater runoff that results from development. This runoff places a burden on sewer systems and degrades aquatic resources when it is not managed adequately. Unmanaged stormwater runoff overloads the capacity of streams and storm sewers and is responsible for increased combined sewer overflow events and adverse downstream impacts, such as flash flooding, channel erosion, surface and groundwater pollution, and habitat degradation.

Recognizing this issue, the District first adopted stormwater management regulations in 1988. These regulations (Chapter 5 of Title 21 of the District of Columbia Municipal Regulations) established requirements to manage both stormwater quality and quantity. Quality control focused on the removal of pollutants from up to the first 0.5 inches of stormwater runoff, often referred to as the “first flush.” Quantity control was mandated through detention requirements based on the 2-year, 24-hour storm event for stream bank protection (widely accepted as the channel shaping flow) and the 15-year, 24-hour storm event for flood protection (the typical design capacity of the District’s sewer conveyance system).

This Stormwater Management Guidebook (SWMG) provides technical guidance on the 2013 revisions to the 1988 regulations. The detention requirements have not changed significantly, but the focus on water-quality treatment has shifted to a standard for volume retention. Major land-disturbing activities must retain the volume from a 1.2-inch storm event, and major substantial improvement activities must retain the volume from a 0.8-inch storm event. By keeping stormwater on site, retention practices effectively provide both treatment and additional volume control, significantly improving protection for District waterbodies. This Stormwater Retention Volume (SWRv) can be managed through runoff prevention (e.g., conservation of pervious cover or reforestation), runoff reduction (e.g., infiltration or water reuse), and runoff treatment (e.g., plant/soil filter systems or permeable pavement).

1.2 Purpose and Scope

The purpose of the SWMG is to provide the technical guidance required to comply with the District’s stormwater management regulations, including the criteria and specifications engineers and planners use to plan, design, and construct regulated sites and stormwater best management practices (BMPs).

It is the responsibility of the design engineer to review, verify, and select the appropriate BMPs and materials for a specific project and submit to DDOE, as required, all reports, design computations, worksheets, geotechnical studies, surveys, rights-of-way determinations, etc. Each such required submittal will bear the seal and signature of the professional engineer licensed to practice in the District who is responsible for that portion of the project.

1.3 Impacts of Urban Runoff

Historically, the collective impacts of rooftops, sidewalks, roadways, and other impervious surfaces on District streams and rivers have been divided into two categories, those attributed to changes in hydrologic response or resulting from human activities. The hydrologic response of an urban area changes when drainage areas become increasingly impervious, causing stormwater runoff volumes, flows, and velocities to increase while base groundwater flows decrease. Small annual storm events that would ideally be captured by the plants and soils of an undeveloped landscape are instead delivered quickly and efficiently through the receiving pipe network to city streams. Human activities in the city, ranging from heavy automobile traffic to use of various chemicals, generate increased pollutant loads. During dry weather, these pollutants combine with deposits of atmospheric pollution from outside of the city to build up on impervious surfaces where rain and snow events later wash them into the District’s sewer pipes, streams, and rivers.

1.3.1 Hydrologic Impacts

Urban development causes significant changes in the rainfall–runoff relationship within a watershed. Rainfall volumes shift from evapotranspiration and infiltration to surface and piped runoff. This shift delivers large amounts of runoff to receiving pipes and streams during even the smallest rainfall event within an urban development (see Figure 1.1).

A city represents a transformation from a natural catchment to a sewershed through an increase in impervious surfaces and the addition of an underground, piped conveyance system. Natural drainage patterns are modified and stormwater runoff is channeled through roof drains, pavement, road gutters, and storm drains. Direct connections between impervious surfaces and stormwater conveyance systems (meant to avoid flooding) deliver these larger volumes more quickly, which leads to an increase in runoff volumes and velocities. The time runoff takes to travel downstream becomes shorter, and infiltration into underlying soils and groundwater aquifers decreases or is eliminated (see Figure 1.2).

The District’s 1988 stormwater management regulations responded to these volume impacts with a focus on “peak matching,” where volume releases were delayed and released at a 2-year flow rate. Recent research has found that this approach has, in many cases, led to an increase in stream erosion because the full runoff volume is still forced through the receiving channel. Even at this low flow rate, the channel is subjected to an elevated flow for prolonged durations.

In addition, a 2-year flow control structure allows the large number of smaller-sized storms to wash off a site at the discharge rate allowed for the 2-year storm, when they should have a lower discharge rate. The District’s new stormwater retention requirements complement and improve peak flow matching by retaining stormwater from these smaller storms on site and reducing the overall runoff volumes that leave the site. Retention is a better approximation of the natural drainage cycle.

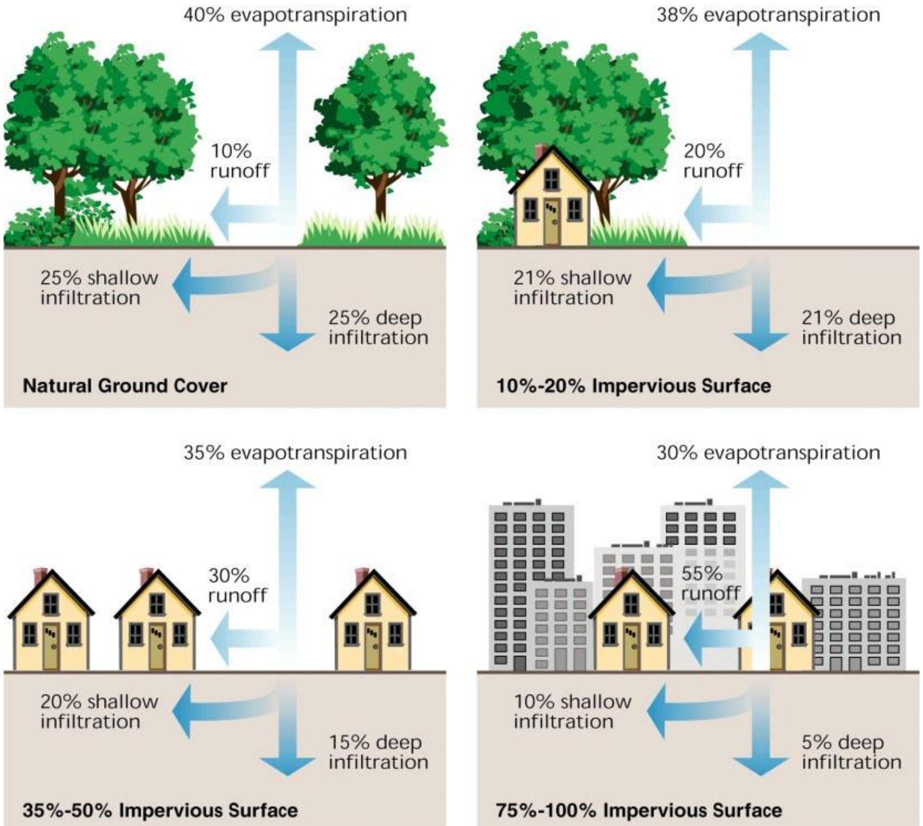

Figure 1.1 Changes in the water balance resulting from urbanization (FISRWG, 1998).

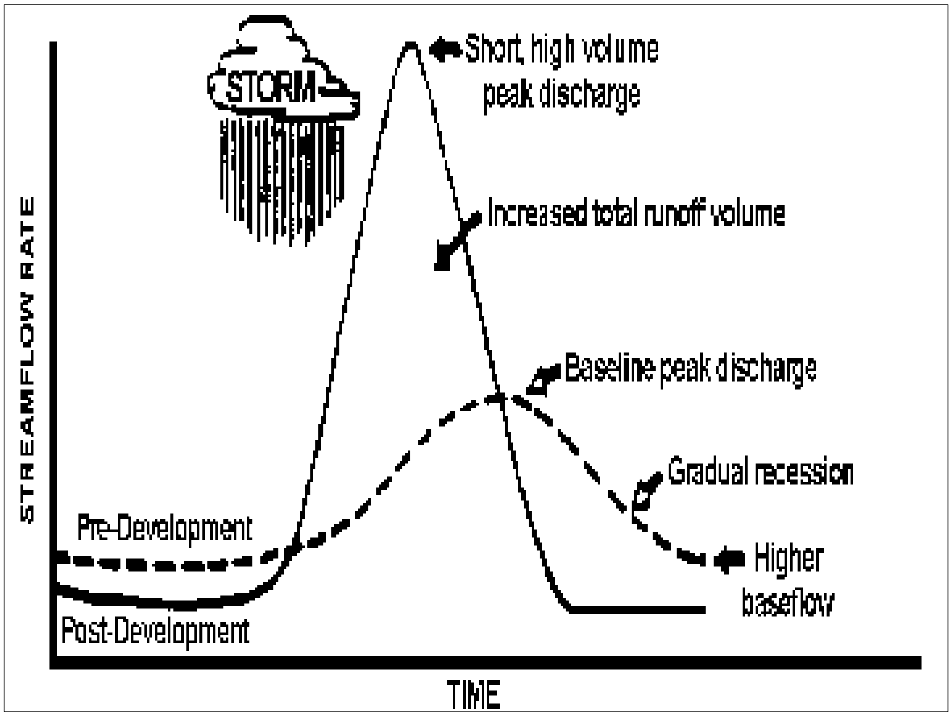

Figure 1.2 Changes in streamflow resulting from urbanization (Schueler, 1987).

1.3.2 Water Quality Impacts

As land is developed, impervious surfaces replace naturally vegetated areas that once allowed water to infiltrate and become purified by the soil. Approximately 43 percent of the District's natural groundcover has been replaced with impervious surfaces, which accumulate pollutants deposited from the atmosphere, leaked from vehicles, or windblown from adjacent areas. During storm events, these pollutants quickly wash off impervious surfaces and are delivered rapidly to downstream waters. Table 1.1 profiles common pollutants found in urban stormwater runoff and their sources.

Table 1.1 Common Pollutants in Urban Stormwater Runoff and Their Sources (SWQTF, 1993)

Pollutant	Automobile/ Atmospheric Deposition	Urban Housekeeping / Landscaping Practices	Industrial Activities	Construction Activities	Connections other than Stormwater	Accidental Spills and Illegal Dumping
Sediments	X	X	X	X		
Nutrients	X	X	X	X	X	X
Bacteria and Viruses	X	X		X	X	X
Oxygen Demanding Substances		X	X	X	X	X
Oil and Grease	X	X	X	X	X	X
Anti-Freeze	X	X		X	X	X
Hydraulic Fluid	X	X	X	X	X	X
Paint		X		X	X	X
Cleaners and Solvents	X	X	X	X	X	X
Wood Preservatives		X		X	X	X
Heavy Metals	X	X	X	X	X	X
Chromium	X	X	X			
Copper	X	X	X			
Lead	X	X	X			
Zinc	X	X	X			
Iron	X		X			
Cadmium	X		X			
Nickel	X		X			
Magnesium	X		X			
Toxic Materials						
Fuels	X		X	X	X	X
PCBs	X				X	X
Pesticides	X	X	X	X	X	X
Herbicides	X		X	X	X	X
Floatables		X	X	X		

1.4 References

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Chapter 2 Minimum Control Requirements

2.1 District of Columbia Stormwater Management Performance Requirements

This chapter presents a unified approach for sizing stormwater best management practices (BMPs) in the District of Columbia (District) to meet pollutant removal goals, reduce peak discharges, and pass extreme floods. Table 2.1 presents a summary of the sizing criteria used to achieve the stormwater management performance requirements for regulated activity.

Those portions of regulated activity that involve the reconstruction of the existing public right-of-way are governed by a "maximum extent practicable" approach, detailed in Appendix B. There are notes throughout this chapter that identify special conditions for regulated activity located in the Anacostia Waterfront Development Zone (AWDZ) that are governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012 (see D.C. Official Code §§ 2-1226.36(c)(1)). Figure 2.1 provides a map that outlines the boundaries of the AWDZ and the exact boundaries are provided in definitions found in Appendix U.

This chapter describes the seven sizing criteria in detail and provides guidance on how to properly compute and manage the required volumes. This chapter also presents an overview of acceptable BMP options that can be used to comply with the sizing criteria. Appendix A provides a line-by-line review of the accompanying calculator spreadsheets.

Note: 2-year post-development peak discharge requirements do not apply to projects when three conditions can be established: (1) site discharges flow directly to, or through the separate sewer system, into the main stem of the tidal Potomac or Anacostia Rivers, the Washington Channel, or the Chesapeake and Ohio Canal; (2) site discharges do not flow into or through a tributary to those waterbodies that runs above ground or that the District Department of the Environment (DDOE) expects to be daylighted to run above ground; and (3) site discharges will not cause erosion of land or transport of sediment.

Table 2.1 Sizing Criteria for Stormwater Management Performance Requirements

Sizing Criteria	Description of Stormwater Sizing Criteria
Stormwater Retention Volume (*SWRv*) (gal)	$SWRv = [P \times [(Rv_I \times \%I) + (Rv_C \times \%C) + (Rv_N \times \%N)] \times SA] \times 7.48/12$ where: $SWRv$ = volume required to be retained on site (gal) P = variable percentile rainfall event for the District dependent on regulatory trigger (see next criterion) Rv_I = 0.95 (runoff coefficient for impervious cover) Rv_C = 0.25 (runoff coefficient for compacted cover) Rv_N = 0.00 (runoff coefficient for natural cover) $\%I$ = percent of site in impervious cover (decimal) $\%C$ = percent of site in compacted cover (decimal) $\%N$ = percent of site in natural cover (decimal) SA = surface area (ft^2) 7.48 = conversion factor, converting cubic feet to gallons 12 = conversion factor, converting inches to feet
Precipitation value selected based on Regulatory Trigger (*P*)	Major Land-Disturbing Activity (AWDZ and District-wide): 90th percentile event (1.2 inches) Major Substantial Improvement Activity (AWDZ): 85th percentile event (1.0 inches) Major Substantial Improvement Activity (District-wide): 80th percentile event (0.8 inches)
Reconstruction of public right-of-way	Consult Appendix B Maximum Extent Practicable Process for Existing Public Right-of-Way
Water Quality Treatment Volume (*WQTv*) (gal) (applies only to regulated activity in the AWDZ area governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012)	$WQTv = (P \times [(Rv_I \times \%I) + (Rv_C \times \%C) + (Rv_N \times \%N) \times SA] \times 7.48/12) - SWRv$ where: $WQTv$ = volume required to be retained or treated, above and beyond the SWRv (gal) $SWRv$ = volume required to be retained on site (gal) P = 95th percentile rain event for the District (1.7 inches) Rv_I = 0.95 (runoff coefficient for impervious cover) Rv_C = 0.25 (runoff coefficient for compacted cover) Rv_N = 0.00 (runoff coefficient for natural cover) $\%I$ = percent of site in impervious cover (decimal) $\%C$ = percent of site in compacted cover (decimal) $\%N$ = percent of site in natural cover (decimal) SA = surface area (ft^2) 7.48 = conversion factor, converting cubic feet to gallons 12 = conversion factor, converting inches to feet
2-Year Storm Control (Qp_2)	The peak discharge rate from the 2-year, 24-hour storm event controlled to the predevelopment peak discharge rate.
15-Year Storm Control (Qp_{15})	The peak discharge rate from the 15-year, 24-hour storm event controlled to the preproject peak discharge rate.
Extreme Flood Requirements (Q_f)	The peak discharge rate from the 100-year storm event controlled to the preproject peak discharge rate if the site: 1) Increases the size of a Special Flood Hazard Area (SFHA) as delineated on the effective Flood Insurance Rate Maps (FIRM) or 2) Meets the following two conditions: (a) Does not discharge to the sewer system and (b) Has a post-development peak discharge rate for a 100-year frequency storm event that will cause flooding to a building.

Figure 2.1 Map of Anacostia Waterfront Development Zone.

2.2 Stormwater Retention Volume

Regulated sites that undergo a major land-disturbing activity or a major substantial improvement activity must employ BMPs and post-development land cover necessary to achieve the stormwater retention volume (SWRv) equal to the post-development runoff from the applicable rainfall event, as measured for a 24-hour storm with a 72-hour antecedent dry period. For a major substantial improvement activity located in the AWDZ, governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012, the applicable rainfall event is the 85th percentile rainfall event (1.0 inches). For all other major substantial improvement activities throughout the District, the applicable rainfall event is the 80th percentile rainfall event (0.8 inches). The SWRv is calculated as follows for the entire site and for each drainage area:

Equation 2.1 Stormwater Retention Volume

$$SWRv = \frac{\{P \times [(Rv_I \times \%I) + (Rv_C \times \%C) + (Rv_N \times \%N)] \times SA\} \times 7.48}{12}$$

where:

SWRv	=	volume required to be retained on site (gal)
P	=	selection of District rainfall event varies based on regulatory trigger; 90th percentile (1.2 inches) for major land-disturbing activity, 85th percentile (1.0 inches) for major substantial improvement activity in the AWDZ and governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012, 80th percentile (0.8 inches) for other major substantial improvement activities
Rv_I	=	runoff coefficient for impervious cover (0.95)
%I	=	percent of site in impervious cover
Rv_C	=	runoff coefficient for compacted cover (0.25)
%C	=	percent of site in compacted cover
Rv_N	=	runoff coefficient for natural cover (0.00)
%N	=	percent of site in natural cover
SA	=	surface area (ft^2)
7.48	=	conversion factor, converting cubic feet to gallons
12	=	conversion factor, converting inches to feet

where the surface area under a BMP shall be calculated as part of the impervious cover (%I); and

A site may achieve on-site retention by directly conveying volume from the regulated site to a shared BMP with available retention capacity. A site may achieve the SWRv on site or through a combination of on-site retention and off-site retention under the following conditions:

- The site shall retain on site a minimum of 50 percent of the SWRv calculated for the entire site, unless DDOE approves an application for relief from extraordinarily difficult site conditions (Appendix E).
- The site shall use off-site retention for the portion of the SWRv that is not retained on site (See Chapter 6 and Appendix C).
- Regulated activity in the AWDZ, governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012, must have all off-site retention approved by DDOE even if the minimum 50 percent on-site requirement has been achieved. These projects may apply to achieve retention compliance with off-site retention based on considerations of technical infeasibility and environmental harm as well as the limited appropriateness of on-site compliance in terms of impact on surrounding landowners or overall benefit to District waterbodies.
- Projects requesting relief from compliance with the minimum on-site retention obligation (50% of the SWRv) and claiming “extraordinarily difficult site conditions” will follow the submission and evaluation process detailed in Appendix E. Sites approved for “relief from

extraordinarily difficult site conditions" are still responsible for the entire SWRv but will be allowed to use off-site retention to achieve more than 50percent of the SWRv.

An individual drainage area is defined as the area that drains to a single discharge point from the site. A site may achieve on-site retention by retaining more than the SWRv in an individual drainage area, subject to the following conditions:

- For each drainage area, as well as for all vehicular access areas within each drainage area, at least 50 percent of the SWRv must be retained or treated with an accepted practice to remove 80 percent of total suspended solids (TSS), unless it drains into the combined sewer system. For vehicular access areas that are part of a submission following the maximum extent practicable (MEP) process, the MEP narrative must address the placement and sizing opportunities and the restrictions of a retention practice where these minimums are not achieved. Figure 2.2 provides a map that outlines the boundaries of the District's Combined Sewer System (CSS) and Municipal Separate Storm Sewer System (MS4).
- Retention in excess of the SWRv for one drainage area may be applied to the retention volume required for another drainage area;
- Retention of volume greater than that from a 1.7-inch rainfall event, calculated using the SWRv equation with a P equal to 1.7 inches, shall not be counted toward on-site retention.

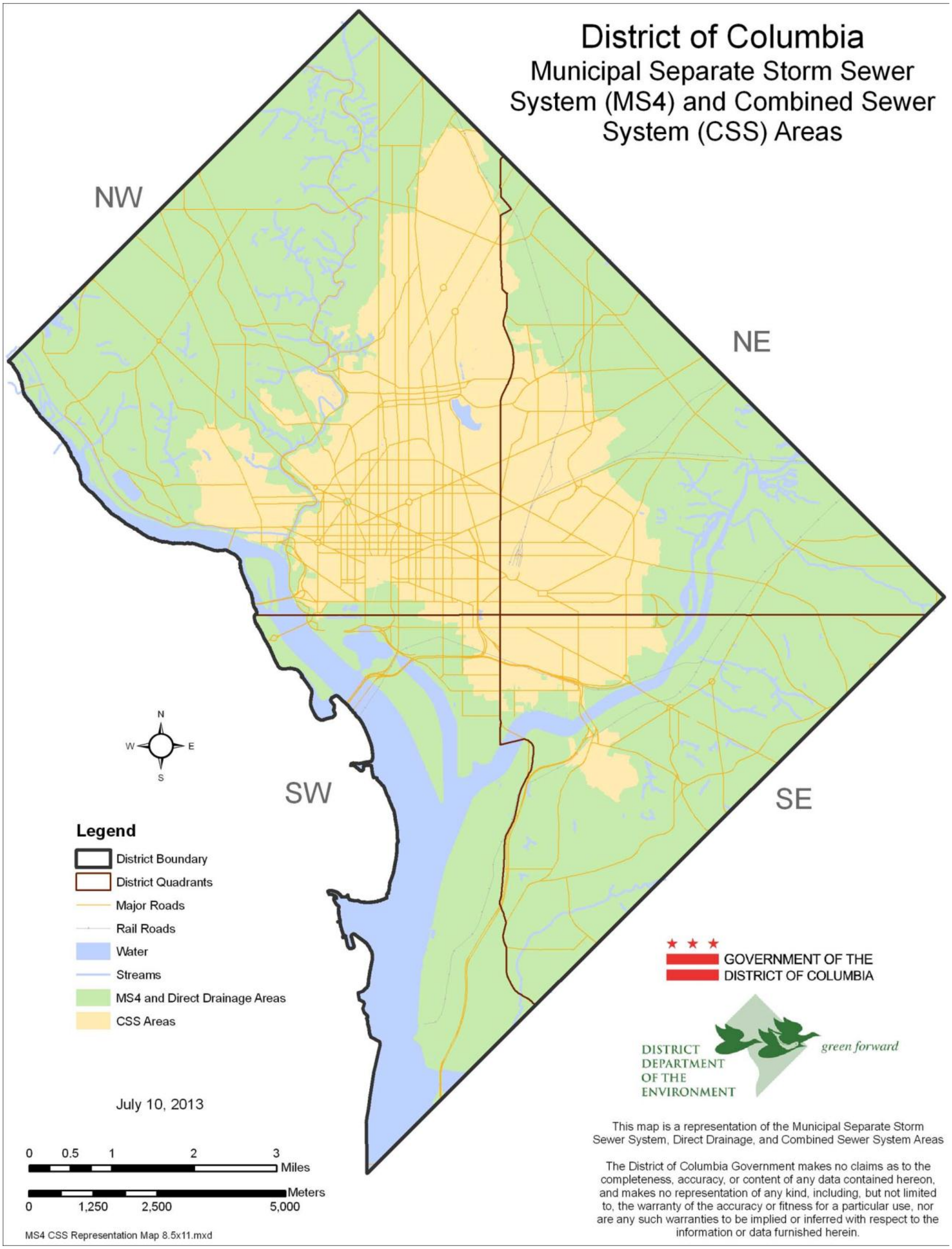


Figure 2.2 Map of District of Columbia MS4 and CSS areas.

The following are "Accepted Practices" by DDOE for treatment to remove 80 percent of TSS:

- Permeable Pavement Systems
- Bioretention
- Stormwater Filtering Systems
- Stormwater Ponds
- Wetlands
- Dry Swales
- Wet Swales
- Proprietary practices that have been demonstrated to achieve an 80 percent reduction in TSS in accordance with the requirements of Appendix S.

Major land-disturbing activities in the existing public right-of-way, including activities associated with a major land-disturbing activity on private property, must achieve the SWRv to the MEP. The MEP design and review process is detailed in Appendix B.

2.3 Water Quality Treatment Volume

In addition to the SWRv requirements above, sites located in the AWDZ and governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012 shall employ BMPs and post-development land cover necessary to achieve a water quality treatment volume (WQTv) equal to the difference between the post-development runoff from the 95th percentile rainfall event (1.7 inches), measured for a 24-hour rainfall event with a 72-hour antecedent dry period, and the SWRv. The WQTv is calculated as follows, for the entire site, and each individual drainage area:

Equation 2.2 Water Quality Treatment Volume

$$WQTv = \{P \times [(Rv_I \times \%I) + (Rv_C \times \%C) + (Rv_N \times \%N)] \times SA\} \times 7.48 - SWRv$$

where:

$WQTv$	=	volume, in gallons, required to be retained or treated, above and beyond the Stormwater Retention Volume (SWRv).
$SWRv$	=	volume, in gallons, required to be retained, as described in Section 2.2
P	=	95th percentile rainfall event for the District (1.7 inches)
Rv_I	=	0.95 (runoff coefficient for impervious cover)
Rv_C	=	0.25 (runoff coefficient for compacted cover)
RvN	=	0.00 (runoff coefficient for natural cover)
$\%I$	=	percent of site in impervious cover
$\%C$	=	percent of site in compacted cover
$\%N$	=	percent of site in natural cover
SA	=	surface area in square feet,

where, the surface area under a BMP shall be calculated as part of the impervious cover (%I); and

A site in the AWDZ that is governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012 may achieve on-site treatment for WQTv with:

- On-site treatment with an accepted treatment practice designed to remove 80 percent of TSS;
- On-site retention; or
- Direct conveyance of stormwater from the site to an approved shared BMP with sufficient available treatment or retention capacity.

An AWDZ site that is governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012 may achieve part of the WQTv by using off-site retention if site conditions make compliance technically infeasible or environmentally harmful and DDOE approves an application for “relief from extraordinarily difficult site conditions.”

An AWDZ site governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012 that achieves 1 gallon of off-Site retention volume (Offv) by using Stormwater Retention Credits (SRCs) certified for retention capacity located outside of the Anacostia watershed shall use 1.25 SRCs for that gallon of Offv.

Figures 2.3–2.7 describe the relationship between a variety of project types, the SWRv, and the WQTv.

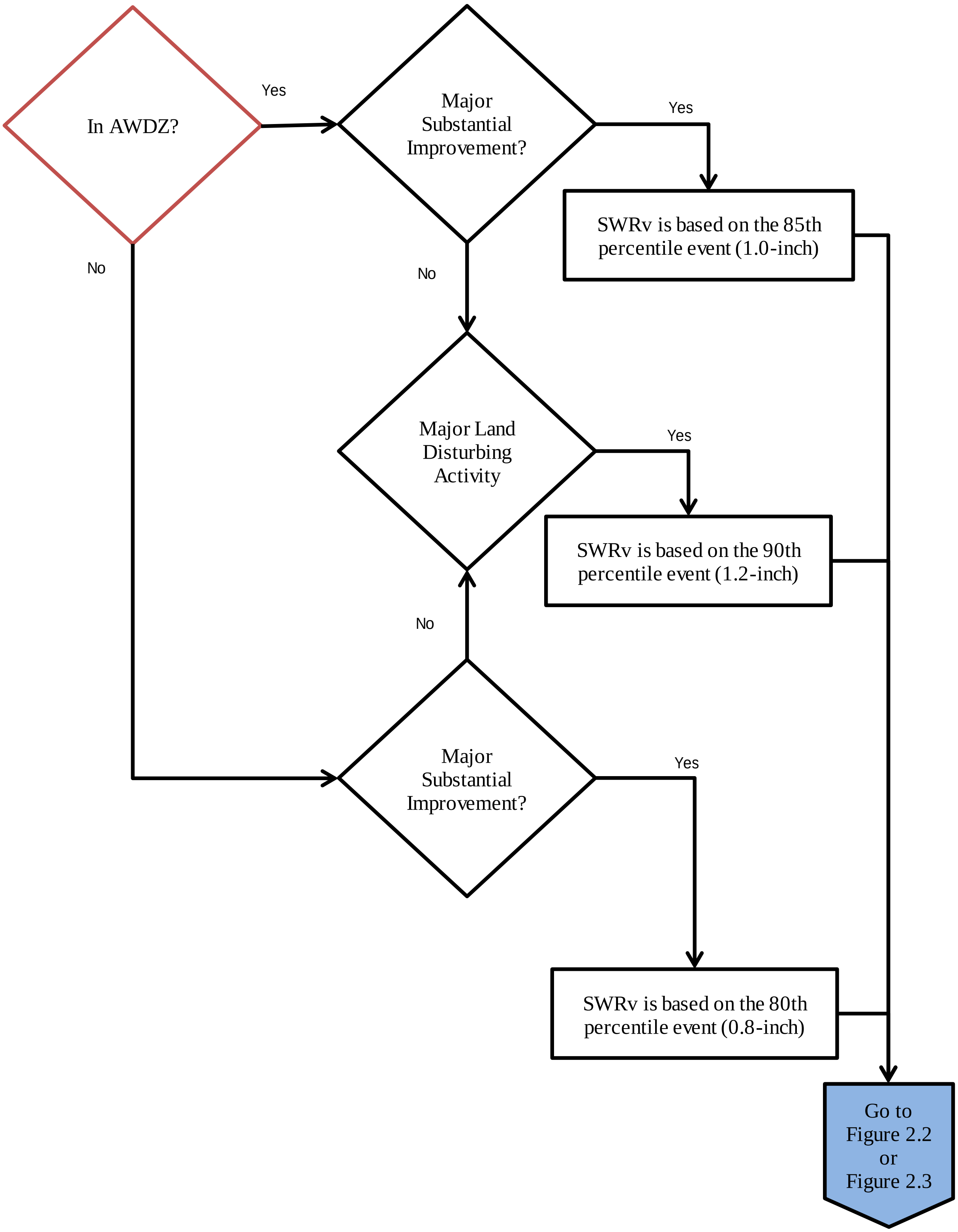


Figure 2.3 Determining the regulatory event used to calculate the SWRv.

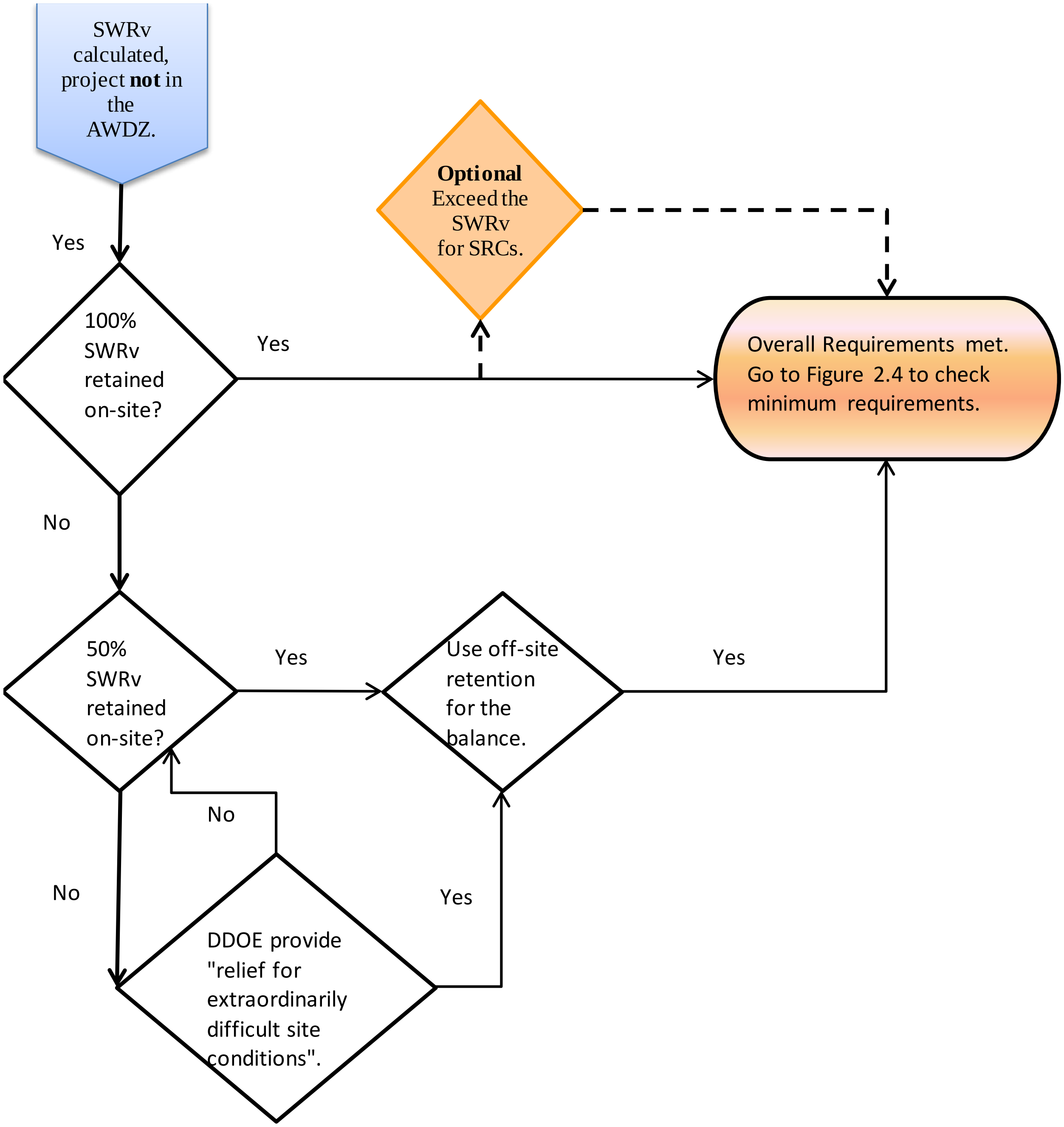


Figure 2.4 Determining if overall retention requirements have been met, outside the AWDZ.

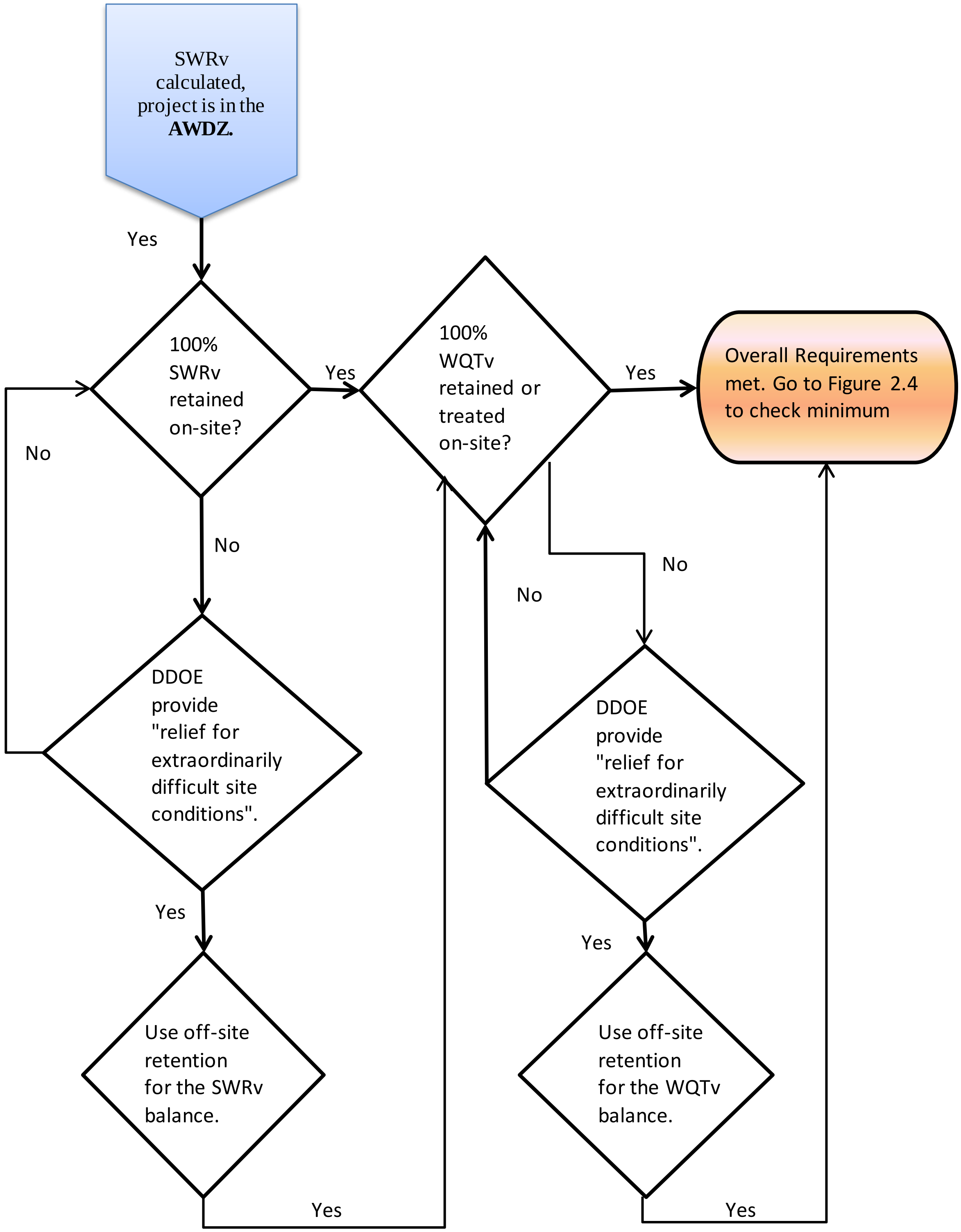
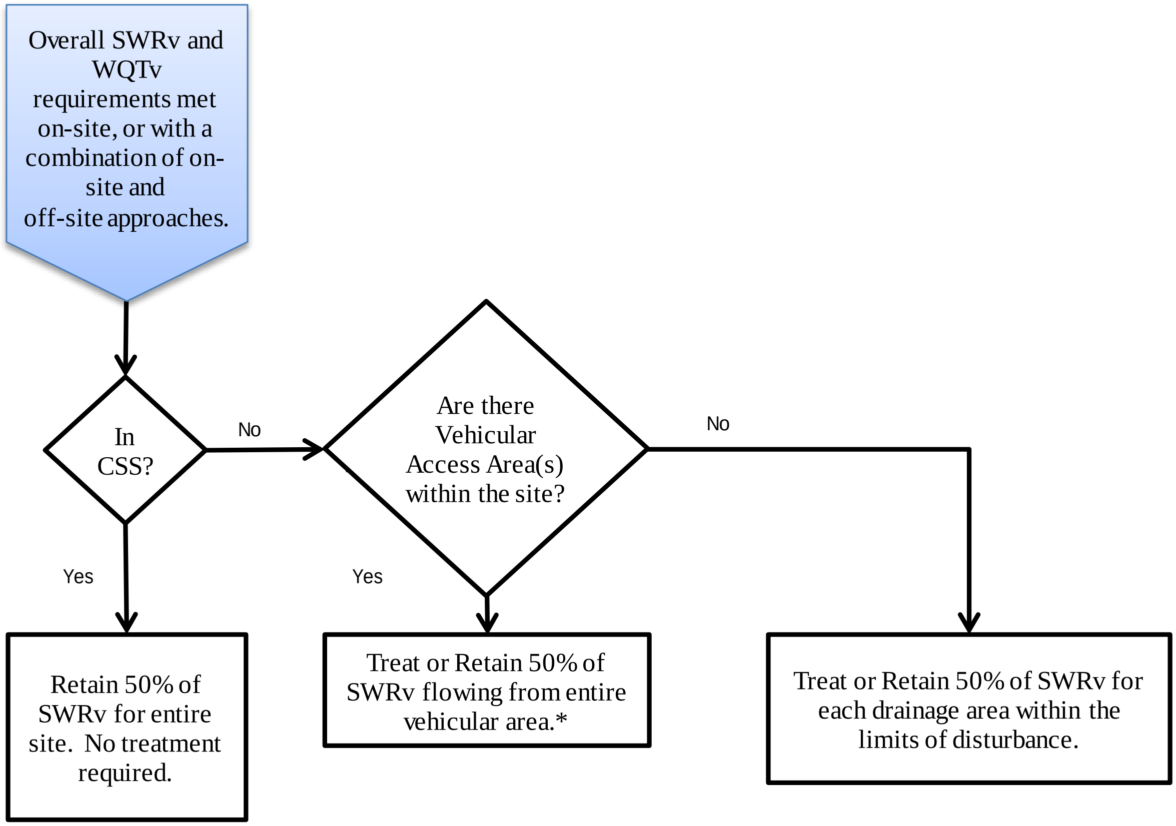


Figure 2.5 Determining if overall retention and water quality treatment requirements have been met, inside the AWDZ for regulated activity governed by the Anacostia Waterfront Environmental Standards Amendment Act of 2012.



* Existing Public right-of-way (PROW) sites follow these guidelines to the maximum extent practicable (MEP). The MEP design and review process is detailed in Appendix B.

Figure 2.6 Determining if minimum retention and water quality treatment requirements have been met.

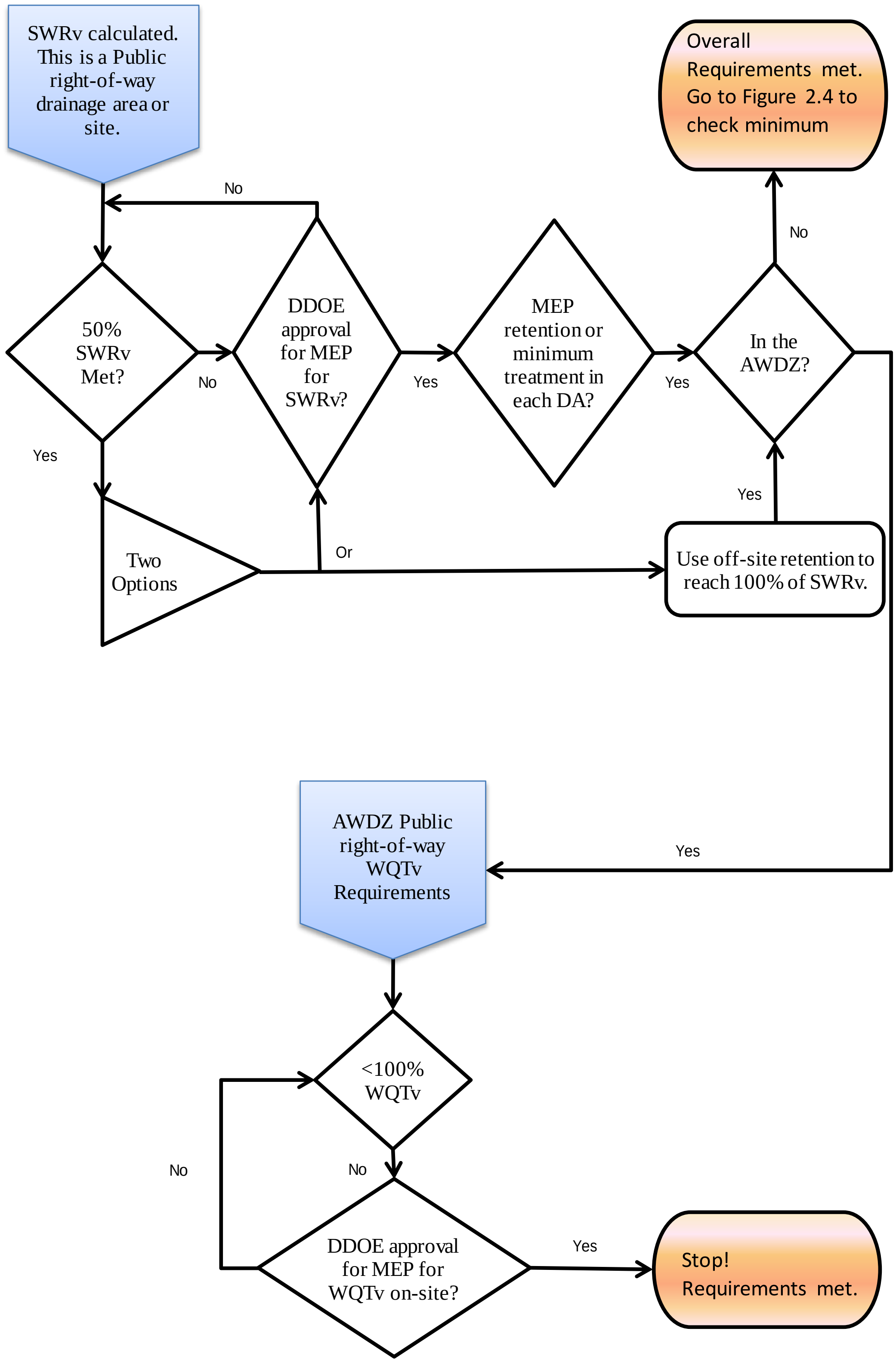


Figure 2.7 Determining retention and water quality requirements for projects in the existing public right-of-way (PROW).

2.4 Extreme Flood Requirements

To meet the extreme flood requirements (Q_f), a site shall maintain the peak discharge rate from the 100-year storm event controlled to the preproject peak discharge rate if the site:

1. Increases the size of a Special Flood Hazard Area (SFHA) as delineated on the effective Flood Insurance Rate Maps (FIRM) or
2. Meets the following two conditions:
   (a) Does not discharge to the sewer system and
   (b) Has a post-development peak discharge rate for a 100-year-frequency storm event that will cause flooding to a building.

The intent of the extreme flood criteria is to (a) prevent flood damage from large storm events, and (b) maintain the boundaries of the 100-year Federal Emergency Management Agency (FEMA) floodplain.

In general, stormwater runoff leaving a development site shall be discharged directly into an adequate natural or man-made receiving channel, pipe, or storm sewer system, or the applicant shall provide a drainage system satisfactory to DDOE to preclude an adverse impact (e.g., soil erosion, sedimentation, flooding, duration of ponding water, inadequate overland relief) on downstream properties and receiving systems. If the applicant chooses to install a drainage system, the system shall be designed in accordance with established, applicable criteria for such systems.

Stormwater runoff leaving a development site where it does not discharge directly to the sewer system shall not aggravate or create a condition where an existing building is flooded from the 100-year storm event. If such a condition exists, on-site detention for the 100-year storm event shall be provided.

In situations where the size of the Special Flood Hazard Area (SFHA) as delineated on the effective Flood Insurance Rate Map (FIRM) by the Federal Emergency Management Agency (FEMA) will be increased based on the increased post-development 100-year discharge, the post-development 100-year peak discharge shall be maintained at a level that is equal to or less than the preproject 100-year peak discharge.

2.5 Minimum Criteria for Determining Extreme Flood Requirements

It is recommended that an applicant use the District’s online Flood Zone Determination Tool (available at http://ddoe.dc.gov/floodplainmap) as an initial screening for this section.

An applicant shall use the following minimum criteria to determine whether extreme flood requirements are applicable:

Downstream Analysis:

1. Consult DDOE to initially determine whether or not the downstream analysis is needed. A site visit is necessary for the determination. This analysis is used to determine the impact of the 100-year post-development discharge on a building.
2. If the analysis is needed, the analysis shall contain supporting computations as justification for the conclusions contained in the analysis. For consistency, the following items are to be included, at a minimum:
   (a) Site-specific narrative with a description of the elements of the storm drainage system, overland relief paths and adjoining properties;
   (b) A drainage plan showing outfall location(s) with the contributing drainage areas for each outfall. Digital pictures of the outfall shall be included;
   (c) A profile for each outfall channel and overland relief path;
   (d) Two cross sections, at a minimum, at each critical location to verify the outfall and overland relief adequacy. Cross sections shall be based on a 2-foot contour interval and additional spot elevations in the vicinity. The cross sections shall have the same vertical and horizontal scales and shall identify the top of banks for the channel;
   (e) Description of the outfall channel and permissible velocity. The Manning's roughness coefficient shall be supported by soil classification, cover material, and channel's or flow path's lining. The description of physical characteristics may include the amount of flow meandering, material classification of the flow path and its banks, vegetation, obstruction to flow, variations in cross sections and surface irregularity;
   (f) Detailed hydrologic and hydraulic (H & H) calculations to obtain the 100-year water surface elevation (WSE). The acceptable methodologies and models are specified in Appendix H;
   (g) Delineation of the 100-year WSE on the project drainage plan to show the location and approximate extent of the overland relief path and areas that may be affected by the surface storage for the 100-year storm event. Overlaying arrows, shading or other suitable see-through graphics are suggested for this purpose; and
   (h) Certification by the District professional engineer that no buildings will be subject to increased flooding by the 100-year post-development discharge from the development site.
3. If buildings will be flooded based on the analysis, then the design engineer must perform more precise hydrologic and hydraulic computations. In addition to the on-site 100-year detention, the applicant shall design the outfall drainage system, overland relief swales, and/or surface storage in such a way that no building will be damaged by flooding.
4. If the protection measures for the outfall drainage system or overland relief path are provided, necessary design details shall be shown and supported by calculations and submitted to DDOE for review.

Hydrologic and Hydraulic Analysis:

1. Consult DDOE to initially determine whether or not the H&H analysis is needed. This analysis is used to determine the impact on SFHA by considering the entire watershed.
2. The acceptable methodologies and models for H&H analysis are specified in Section 2.7 and further described in Appendix H.
3. H&H investigations may be required to demonstrate that downstream roads, bridges, and public utilities are adequately protected from the Q_f storm. These investigations typically extend to the first downstream tributary of equal or greater drainage area or to any downstream dam, highway, or natural point of restricted stream flow.

2.6 Additional Stormwater Management Requirements

Any BMP that may receive stormwater runoff from areas that are potential sources of oil and grease contamination (concentrations exceeding 10 milligrams per liter) shall include a baffle, skimmer, oil separator, grease trap, or other mechanism that prevents oil and grease from escaping the BMP in concentrations exceeding 10 milligrams per liter.

Any BMP that receives stormwater runoff from areas used to confine animals may be required connect to a sanitary or combined sewer and to meet DC Water's pretreatment requirements.

2.7 Hydrology Methods

The following are the acceptable methodologies and computer models for estimating runoff hydrographs before and after development. These methods are used to predict the runoff response from given rainfall information and site surface characteristic conditions. The design storm frequencies used in all of the hydrologic engineering calculations will be based on design storms required in this guidebook unless circumstances make consideration of another storm intensity criteria appropriate.

- Urban Hydrology for Small Watersheds TR-55
- Storage-Indication Routing
- HEC-HMS, WinTR-55, TR-20, and SWMM Computer Models
- Rational Method (limited to sites under 5 acres)

These methods are given as valid in principle, and are applicable to most stormwater management design situations in the District. Other methods may be used when the District reviewing authority approves their application.

The use of the Natural Resource Conservation Service's (NRCS's) Storage Indication Routing method or an equivalent acceptable method may be required to route the design storms through stormwater facilities. A modified version of the NRCS Curve Number method is provided for computing the peak discharge for the SWRv 1.2-inch rain event. See Appendix H for further details and guidance on both computation procedures.

2.8 Acceptable Urban BMP Options

This section sets forth 13 acceptable groups of BMPs that can be used to meet the SWRv and/or peak flow (Qp_2, Qp_{15}, Q_f) criteria.

The dozens of different BMP designs currently used in the District are assigned to 13 general categories for stormwater quality control:

BMP Group 1	Green Roofs
BMP Group 2	Rainwater Harvesting
BMP Group 3	Impervious Surface Disconnection
BMP Group 4	Permeable Pavement Systems
BMP Group 5	Bioretention
BMP Group 6	Filtering Systems
BMP Group 7	Infiltration
BMP Group 8	Open Channel Systems
BMP Group 9	Ponds
BMP Group 10	Wetlands
BMP Group 11	Storage Practices
BMP Group 12	Proprietary Practices
BMP Group 13	Tree Planting and Preservation

Within each BMP group, detailed performance criteria are presented that govern feasibility, conveyance, pretreatment, treatment, landscaping, construction sequence, maintenance, and stormwater retention calculations (see Chapter 3).

Guidance on selecting the most appropriate combination of BMPs is provided in Chapter 4.

BMP Group 1 Green Roofs

Green roofs are BMPs that capture and store rainfall, which would otherwise land on an impervious rooftop, in an engineered growing media that is designed to support plant growth. A portion of the captured rainfall evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads. Design variants include:

G-1 Extensive green roofs have a much shallower growing media layer that typically ranges from 3 to 6 inches thick.

G-2 Intensive green roofs have a growing media layer that ranges from 6 inches to 4 feet thick.

BMP Group 2 Rainwater Harvesting

Rain water harvesting systems intercept, divert, store, and release rainfall for future use. Rainwater that falls on a rooftop is collected and conveyed into an above- or below-ground storage tank (also referred to as a cistern or rain tank), where it can be used for non-potable water uses and on-site stormwater disposal/infiltration.

BMP Group 3 Impervious Surface Disconnection

This strategy involves managing runoff close to its source by intercepting, infiltrating, filtering, treating, or reusing it as it moves from the impervious surface to the drainage system. Simple disconnection variants include:

D-1 Simple disconnection to a pervious compacted cover area

D-2 Simple disconnection to a conserved natural cover area

D-3 Simple disconnection to a soil compost amended filter path

Disconnection can also be employed as part of infiltration, bioretention, and rainwater harvesting systems.

BMP Group 4 Permeable Pavement Systems

Permeable pavement is an alternative paving surface that captures and temporarily stores the design volume by filtering runoff through voids in the pavement surface into an underlying stone reservoir. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially infiltrate into the soil. Design variants include:

P-1 Porous asphalt (PA)

P-2 Pervious concrete (PC)

P-3 Permeable pavers (PP)

BMP Group 5 Bioretention

Bioretention facilities are BMPs that capture and store stormwater runoff and pass it through a filter bed of engineered soil media comosed of sand, soil, and organic matter. Filtered runoff may be collected and returned to the conveyance system, or allowed to infiltrate into the soil. Design variants include:

B-1 Traditional bioretention

B-2 Streetscape bioretention

B-3 Engineered tree pits

B-4 Stormwater planters

B-5 Residential rain gardens

BMP Group 6 Filtering Systems

Filtering systems are BMPs that capture and temporarily store the design volume and pass it through a filter bed of sand, organic matter, soil or other filtering media. Filtered runoff may be collected and returned to the conveyance system. Design variants include:

F-1 Non-structural sand filter

F-2 Surface sand filter

F-3 Three-chamber underground sand filter

F-4 Perimeter sand filter

BMP Group 7 Infiltration BMPs

Infiltration BMPs capture and store the design volume before allowing it to infiltrate into the soil over a 48-hour period. Design variants include:

I-1 Infiltration trench

I-2 Infiltration basin

BMP Group 8 Open Channel BMPs

Open channel BMPs are vegetated open channels that are designed to capture and treat or convey the design storm volume. Design variants include:

O-1 Grass channels

O-2 Dry swale

O-3 Wet swale

BMP Group 9 Ponds

Stormwater ponds are stormwater storage BMPs that consist of a combination of a permanent pool, micropool, or shallow marsh that promote a good environment for gravitational settling, biological uptake, and microbial activity. Design variants include:

P-1 Micropool extended detention pond

P-2 Wet pond

P-3 Wet extended detention (ED) pond

BMP Group 10 Wetlands

Stormwater wetlands are BMPs that create shallow marsh areas to treat urban stormwater which often incorporate small permanent pools and/or extended detention storage. Stormwater wetlands are explicitly designed to provide stormwater detention for larger storms (2-year, 15-year or flood control events) above the SWRv. Design variants include:

W-1 Shallow wetland

W-2 Extended detention (ED) shallow wetland

BMP Group 11 Storage Practices

Storage practices are explicitly designed to provide stormwater detention (2-year, 15-year, and/or flood control). Storage practices alone are not considered acceptable practices to meet the SWRv or TSS removal requirements. Design variants include:

S-1 Underground vault

S-2 Dry pond

S-3 Rooftop storage

S-4 Stone storage under permeable pavement or other BMPs

Design guidance and criteria for the practice of rooftop storage is provided in Appendix I.

BMP Group 12 Proprietary Practices

Proprietary practices are manufactured stormwater BMPs that utilize settling, filtration, absorptive/adsorptive materials, vortex separation, vegetative components, and/or other appropriate technology to manage the impacts of stormwater runoff.

Proprietary practices may meet the SWRv value as well as the TSS removal value, provided they have been approved by DDOE through the process detailed in Appendix S.

BMP Group 13 Tree Planting and Preservation

Trees can significantly reduce stormwater runoff by canopy interception and uptake of water from the soil. Trees are well documented in their ability to reduce stormwater runoff, particularly when the tree canopy covers impervious surface, such as in the case of street trees.

Chapter 3 Stormwater Best Management Practices (BMPs)

3.1 Standard Best Management Practice Design Guidance Format

This chapter outlines performance criteria for 13 stormwater best management practice (BMP) categories that include green roofs, rainwater harvesting, impermeable surface disconnection, permeable pavement, bioretention, filtering systems, infiltration practices, storage practices, ponds, wetlands, open channels, proprietary practices, and tree planting.

BMP performance criteria are based on several critical design factors to ensure effective and long-lived BMPs. Design components that differ from these specifications but meet their intent may be included at the District Department of the Environment's (DDOE's) discretion. In this chapter, and throughout the guidebook, the terms "must" or "shall" denote required aspects of BMPs or their design and implementation, while the term "should" denotes a recommendation. However, justification may be necessary for design or implementation that does not correspond to certain recommendations.

For each BMP, the following factors are discussed:

- General Feasibility
- Conveyance
- Pretreatment
- Design and Sizing
- Landscaping
- Construction Sequencing
- Maintenance
- Stormwater Compliance Calculations

3.2 Green Roofs

Definition. Practices that capture and store rainfall in an engineered growing media that is designed to support plant growth. A portion of the captured rainfall evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development 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. Extensive green roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation and requires minimal, infrequent fertilization after vegetation is initially established.

Design variants include extensive and intensive green roofs.

G-1 Extensive green roofs have a much shallower growing media layer that typically ranges from 3 to 6 inches thick.

G-2 Intensive green roofs have a growing media layer that ranges from 6 to 48 inches thick.

Green roofs are typically not designed to provide stormwater detention of larger storms (e.g., 2-year, 15-year) although some intensive green roof systems may be designed to meet these criteria. Most green roof designs shall generally be combined with a separate facility to provide large storm controls.

This specification is intended for situations where the primary design objective of the green roof is stormwater management and, unless specified otherwise, addresses the design of extensive roof systems. While rooftop practices such as urban agriculture may provide some retention, their primary design objective is not stormwater management and is not addressed in this specification.

3.2.1 Green Roof Feasibility Criteria

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. Key constraints with green roofs include the following:

Structural Capacity of the Roof. When designing a green roof, designers must not only consider the stormwater storage capacity of the green roof but also its structural capacity to support the weight of the additional water. A conventional rooftop should typically be designed to support an additional 15 to 30 pounds per square foot (psf) for an extensive green roof. As a result, 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. See Section 3.2.4 Green Roof Design Criteria for more information on structural design considerations.

Roof Pitch. Green roof storage volume is maximized on relatively flat roofs (a pitch of 1 to 2 percent). 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 30 percent if baffles, grids, or strips are used to prevent slippage of the media. These baffles must be designed to ensure the roof provides adequate storage for the design storm. Slopes greater than 30 percent would be considered a green wall, which is not specifically identified as a stormwater best management practice (BMP). Green walls can be used to receive cistern discharge (calculations are necessary to determine demand) and can be used to comply with Green Area Ratio Requirements.

Roof Access. Adequate access to the roof must be available to deliver construction materials and perform routine maintenance. Roof access can be achieved either by an interior stairway through a penthouse or by an alternating tread device with a roof hatch or trap door not less than 16 square feet in area and with a minimum dimension of 24 inches (NVRC, 2007). Designers should also consider how they will get construction materials up to the roof (e.g., by elevator or crane) and how the roof structure can accommodate material stockpiles and equipment loads. If material and equipment storage is required, rooftop storage areas must be identified and clearly marked based on structural load capacity of the roof.

Roof Type. Green roofs can be applied to most roof surfaces. Certain roof materials, such as exposed treated wood and uncoated galvanized metal, may not be appropriate for green rooftops due to pollutant leaching through the media (Clark et al, 2008).

Setbacks. Green roofs should not be located near rooftop electrical and HVAC systems. A 2-foot wide vegetation-free zone is recommended along the perimeter of the roof with a 1-foot vegetation-free zone around all roof penetrations, to act as a firebreak. The 2-foot setback may be relaxed for small or low green roof applications where parapets have been properly designed.

Contributing Drainage Area. It is recommended that the entire contributing drainage area to a green roof (including the green roof itself) be no more than 25 percent larger than the area of the green roof. In cases where the area exceeds this threshold, the designer must provide supporting documentation of rooftop loading, sufficient design to distribute runoff throughout the green roof and prevent erosion of the roof surface, and justification for incorporating a sizable external drainage area to the green roof.

District Building Codes. The green roof design must comply with the District's building codes with respect to roof drains and emergency overflow devices. Additionally, a District of Columbia registered structural engineer must certify that the design complies with District Building structural codes. This is true for new construction as well as retrofit projects.

3.2.2 Green Roof Conveyance Criteria

The green roof drainage layer (refer to Section 3.2.4) must convey flow from under the growing media directly to an outlet or overflow system such as a traditional rooftop downspout drainage system. The green roof drainage layer must be adequate to convey the volume of stormwater equal to the flow capacity of the overflow or downspout system without backing water up onto the rooftop or into the green roof media. Roof drains immediately adjacent to the growing media should be boxed and protected by flashing extending at least 3 inches above the growing media to prevent clogging. However, an adequate number of roof drains that are not immediately adjacent to the growing media must be provided so as to allow the roof to drain without 3 inches of ponding above the growing media.

3.2.3 Green Roof Pretreatment Criteria

Pretreatment is not necessary for green roofs.

3.2.4 Green Roof Design Criteria

Structural Capacity of the Roof. Green roofs can be limited by the additional weight of the fully saturated soil and plants, in terms of the physical capacity of the roof to bear structural loads. The designer shall consult with a licensed structural engineer to ensure that the building will be able to support the additional live and dead structural load and to determine the maximum depth of the green roof system and any needed structural reinforcement. Typically, the green roof manufacturer can provide specific background specifications and information on their product for planning and design.

In most cases, fully saturated extensive green roofs have loads of about 15 to 30 pounds per square foot, which is fairly similar to traditional new rooftops (12 to 15 pounds per square foot) that have a waterproofing layer anchored with stone ballast. For a discussion of green roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009) and ASTM E-2397, Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems.

Functional Elements of a Green Roof System. A green roof is composed of up to nine different systems or layers that combine to protect the roof and maintain a vigorous cover (see Figure 3.1).

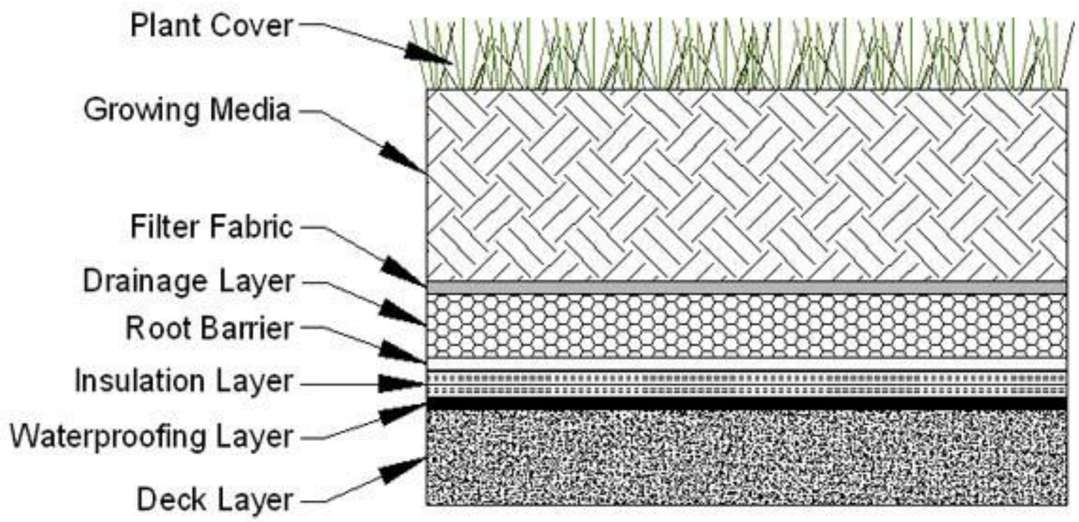


Figure 3.1 Typical layers for a green roof. Note: the relative placement of various layers may vary depending on the type and design of the green roof system.

The design layers include the following:

1. **Deck Layer**. The roof deck layer is the foundation of a green roof. It may be composed of concrete, wood, metal, plastic, gypsum, or a composite material. The type of deck material determines the strength, load bearing capacity, longevity, and potential need for insulation in the green roof system.
2. **Leak Detection System (optional).** Leak detection systems are often installed above the deck layer to identify leaks, minimize leak damage through timely detection, and locate leak locations.
3. **Waterproofing Layer.** All green roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. A wide range of waterproofing materials can be used, including hot applied rubberized asphalt, built up bitumen, modified bitumen, thermoplastic membranes, polyvinyl chloride (PVC), thermoplastic olefin membrane (TPO), and elastomeric membranes (EPDM) (see Weiler and Scholz-Barth, 2009, and Snodgrass and Snodgrass, 2006). The waterproofing layer must be 100 percent waterproof and have an expected life span as long as any other element of the green roof system. The waterproofing material may be loose laid or bonded (recommended). If loose laid, overlapping and additional construction techniques should be used to avoid water migration.
4. **Insulation Layer.** Many green rooftops contain an insulation layer, usually located above, but sometimes below, the waterproofing layer. The insulation increases the energy efficiency of the building and/or protects the roof deck (particularly for metal roofs). According to Snodgrass and Snodgrass (2006), the trend is to install insulation on the outside of the building, in part to avoid mildew problems. The designer should consider the use of open or closed cell insulation depending on whether the insulation layer is above or below the waterproofing layer (and thus exposed to wetness), with closed cell insulation recommended for use above the waterproofing layer.
5. **Root Barrier.** Another layer of a green roof system, which can be either above or below the insulation layer depending on the system, is a root barrier that protects the waterproofing membrane from root penetration. A wide range of root barrier options are described in Weiler and Scholz-Barth (2009). Chemical root barriers or physical root barriers which have been impregnated with pesticides, metals, or other chemicals that could leach into stormwater runoff, must be avoided in systems where the root barrier layer will come in contact with water or allow water to pass through the barrier.
6. **Drainage Layer and Drainage System.** A drainage layer is then placed between the root barrier and the growing media to quickly remove excess water from the vegetation root zone. The selection and thickness of the drainage layer type is an important design decision that is governed by the desired stormwater storage capacity, the required conveyance capacity, and the structural capacity of the rooftop. The effective depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive green roof system and increases for intensive designs. The drainage layer should consist of synthetic or inorganic materials (e.g., 1-2 inch layer of clean, washed granular material (ASTM D448 size No. 8 stone or lightweight granular mix), high density polyethylene (HDPE)) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as

a traditional system of protected roof drains, conductors, and roof leaders. ASTM E2396 and E2398 can be used to evaluate alternative material specifications.

7. **Root-Permeable Filter Fabric**. A semi-permeable needled polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it. The filter fabric must not impede the downward migration of water into the drainage layer.

8. **Growing Media.** The next layer in an extensive green roof is the growing media, which is typically 3 to 6 inches deep (minimum 3 inches). The recommended growing media for extensive green roofs is typically composed of approximately 70 to 80 percent lightweight inorganic materials, such as expanded slates, shales or clays; pumice; scoria; or other similar materials. The remaining media must contain no more than 30 percent organic matter, normally well-aged compost (see Appendix J). The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. The growing media typically has a maximum water retention of approximately 30 percent. Proof of growing media maximum water retention must be provided by the manufacturer. It is advisable to mix the media in a batch facility prior to delivery to the roof. As there are many different types of proprietary growing medias and roof systems, the values provided here are recommendations only. Manufacturer's specifications should be followed for all proprietary roof systems. More information on growing media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006).

   The composition of growing media for intensive green roofs may be different, and it is often much greater in depth (e.g., 6 to 48 inches). If trees are included in the green roof planting plan, the growing media must be sufficient to provide enough soil volume for the root structure of mature trees.

9. **Plant Cover.** The top layer of an extensive green roof typically consists of plants that are non-native, slow-growing, shallow-rooted, perennial, and succulent. These plants are chosen for their ability to withstand harsh conditions at the roof surface. Guidance on selecting the appropriate green roof plants can often be provided by green roof manufacturers and can also be found in Snodgrass and Snodgrass (2006). A mix of base ground covers (usually *Sedum* species) and accent plants can be used to enhance the visual amenity value of a green roof. See Section 3.2.4 Green Roof Design Criteria for additional plant information. The design must provide for temporary, manual, and/or permanent irrigation or watering systems, depending on the green roof system and types of plants. For most application, some type of watering system should be accessible for initial establishment or drought periods. The use of water efficient designs and/or use of non-potable sources are strongly encouraged.

Material Specifications. Standard specifications for North American green roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. The ASTM has recently issued several overarching green roof standards, which are described and referenced in Table 3.1 below.

Designers and reviewers should also fully understand manufacturer specifications for each system component, particularly if they choose to install proprietary "complete" green roof systems or modules.

Table 3.1 Extensive Green Roof Material Specifications

Material	Specification
Roof	Structural capacity must conform to ASTM E-2397-05, *Practice for Determination of Live Loads and Dead Loads Associated with Vegetative (Green) Roof Systems*. In addition, use standard test methods ASTM E2398-05 for *Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems* and ASTME 2399-05 for *Maximum Media Density for Dead Load Analysis*.
Leak Detection System	Optional system to detect and locate leaks in the waterproof membrane.
Waterproof Membrane	See Chapter 6 of Weiler and Scholz-Barth (2009) for waterproofing options that are designed to convey water horizontally across the roof surface to drains or gutter. This layer may sometimes act as a root barrier.
Root Barrier	Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	Depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive designs. The drainage layer should consist of synthetic or inorganic materials (e.g., gravel, high density polyethylene (HDPE), etc.) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors, and roof leaders. Designers should consult the material specifications as outlined in ASTM E2396 and E2398. Roof drains and emergency overflow must be designed in accordance with the District's construction code (DCMR, Title 12).
Filter Fabric	Generally needle-punched, non-woven, polypropylene geotextile, with the following qualities: ▪ Strong enough and adequate puncture resistance to withstand stresses of installing other layers of the green roof. Density as per ASTM D3776 ≥ 8 oz/yd^2. Puncture resistance as per ASTM D4833 ≥ 130 lb. These values can be reduced with submission of a Product Data Sheet and other documentation that demonstrates applicability for the intended use. ▪ Adequate tensile strength and tear resistance for long term performance. ▪ Allows a good flow of water to the drainage layer. Apparent Opening Size, as per ASTM D4751, of ≥ 0.06mm ≤ 0.2mm, with other values based on Product Data Sheet and other documentation as noted above. ▪ Allows at least fine roots to penetrate. ▪ Adequate resistance to soil borne chemicals or microbial growth both during construction and after completion since the fabric will be in contact with moisture and possibly fertilizer compounds.
Growth Media	70% to 80% lightweight inorganic materials and a maximum of 30% organic matter (e.g., well-aged compost). Media typically has a maximum water retention of approximately 30%. Material makeup and proof of maximum water retention of the growing media must be provided. Media must provide sufficient nutrients and water holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM E2396-05.
Plant Materials	*Sedum*, herbaceous plants, and perennial grasses that are shallow-rooted, low maintenance, and tolerant of direct sunlight, drought, wind, and frost. See ASTM E2400-06, *Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems*.

Green Roof Sizing. Green roof areas can be designed to capture the entire Stormwater Retention Volume (SWRv). In some cases, they could be designed to capture larger design storm volumes as well. The required size of a green roof will depend on several factors, including maximum water retention of the growing media and the underlying drainage and storage layer materials (e.g., prefabricated water cups or plastic modules). As maximum water retention can vary significantly between green roof products, verification of this value must be included with the Stormwater Management Plan (SWMP). ASTM tests E2396, E2397, E2398, or E2399, as appropriate, and performed by an ASTM-certified lab are considered acceptable verification. In the absence of ASTM test results the baseline default values must be used. Site designers and planners should consult with green roof manufacturers and material suppliers as they can often provide specific sizing information and hydrology design tools for their products. Equation 3.1 below shall be used to determine the storage volume retained by a green roof.

Equation 3.1 Storage Volume for Green Roofs

$$Sv = \frac{SA \times [(d \times \eta_1) + (DL \times \eta_2)]}{12}$$

where:

Sv	=	storage volume (ft^3)
SA	=	green roof area (ft^2)
d	=	media depth (in.) (minimum 3 in.)
η_1	=	verified media maximum water retention (use 0.15 as a baseline default in the absence of verification data)
DL	=	drainage layer depth (in.)
η_2	=	verified drainage layer maximum water retention (use 0.15 as a baseline default in the absence of verification data)

The appropriate Sv can then be compared to the required SWRv for the entire rooftop area (including all conventional roof areas) to determine the portion of the design storm captured.

Green roofs can have dramatic rate attenuation effects on larger storm events and may be used, in part, to manage a portion of the 2-year and 15-year events. Designers can model various approaches by factoring in storage within the drainage layer. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

3.2.5 Green Roof Landscaping Criteria

Plant selection, landscaping, and maintenance are critical to the performance and function of green roofs. Therefore, a landscaping plan shall be provided for green roofs.

A planting plan must be prepared for a green roof by a landscape architect, botanist, or other professional experienced with green roofs and submitted with the SWMP.

Plant selection for green roofs is an integral design consideration, which is governed by local climate and design objectives. The primary ground cover for most green roof installations is a hardy, low-growing succulent, such as *Sedum*, *Delosperma*, *Talinum*, *Semperivum*, or *Hieracium* that is matched to the local climate conditions and can tolerate the difficult growing conditions found on building rooftops (Snodgrass and Snodgrass, 2006).

A list of some common green roof plant species that work well in the Chesapeake Bay watershed can be found in Table 3.2 below.

Table 3.2 Ground Covers Appropriate for Green Roofs in the District of Columbia

Plant	Light	Moisture Requirement	Notes
Delosperma cooperii	Full Sun	Dry	Pink flowers; grows rapidly
Delosperma 'Kelaidis'	Full Sun	Dry	Salmon flowers; grows rapidly
Delosperma nubigenum 'Basutoland'	Full Sun	Moist-Dry	Yellow flowers; very hardy
Sedum album	Full Sun	Dry	White flowers; hardy
Sedum lanceolatum	Full Sun	Dry	Yellow flowers; native to U.S.
Sedum oreganum	Part Shade	Moist	Yellow flowers; native to U.S.
Sedum stoloniferum	Sun	Moist	Pink flowers; drought tolerant
Sedum telephiodes	Sun	Dry	Blue green foliage; native to region
Sedum ternatum	Part Shade	Dry-Moist	White flowers; grows in shade
Talinum calycinum	Sun	Dry	Pink flowers; self-sows

Note: Designers should choose species based on shade tolerance, ability to sow or not, foliage height, and spreading rate. See Snodgrass and Snodgrass (2006) for a definitive list of green roof plants, including accent plants.

- Plant choices can be much more diverse for deeper intensive green roof systems. Herbs, forbs, grasses, shrubs, and even trees can be used, but designers should understand they may have higher watering, weeding, and landscape maintenance requirements.
- The species and layout of the planting plan must reflect the location of the building, in terms of its height, exposure to wind, snow loading, heat stress, orientation to the sun, and impacts from surrounding buildings. (Wind scour and solar burning have been observed on green roof installations that failed to adequately account for neighboring building heights and surrounding window reflectivity.) In addition, plants must be selected that are fire resistant and able to withstand heat, cold, and high winds.
- 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. The planting plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on green roof plant selection, consult Snodgrass and Snodgrass (2006).

- It is also important to note that most green roof plant species will not be native to the Chesapeake Bay watershed (which contrasts with native plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
- Given the limited number of green roof plant nurseries in the region, it may be necessary for designers to order plants 6 to 12 months prior to the expected planting date. It is also advisable to have plant materials contract grown.
- When appropriate species are selected, most green roofs will not require supplemental irrigation, except for temporary irrigation during drought or initial establishment. The design must provide for temporary, manual, and/or permanent irrigation or watering systems, and the use of water efficient designs and/or use of non-potable sources is strongly encouraged. The planting window extends from the spring to early fall; although, it is important to allow plants to root thoroughly before the first killing frost. Green roof manufacturers and plant suppliers may provide guidance on planting windows as well as winter care. Proper planting and care may also be required for plant warranty eligibility.
- Plants can be established using cuttings, plugs, mats, and, more rarely, seeding or containers. Several vendors also sell mats, rolls, or proprietary green roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006).
- The goal for green roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation that is self-sustaining (not requiring fertilizer inputs) and requires minimal mowing, trimming, and weeding.

The green roof design should include non-vegetated walkways (e.g., paver blocks) to allow for easy access to the roof for weeding and making spot repairs (see Section 3.2.4 Green Roof Design Criteria).

3.2.6 Green Roof Construction Sequence

Green Roof Installation. Given the diversity of extensive vegetated roof designs, there is no typical step-by-step construction sequence for proper installation. The following general construction considerations are noted:

- Construct the roof deck with the appropriate slope and material.
- Install the waterproofing method, according to manufacturer’s specifications.
- Conduct a flood test to ensure the system is watertight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system. Alternately, electric field vector mapping (EFVM) can be done to test for the presence of leaks; however, not all impermeable membranes are testable with this method. Problems have been noted with the use of EFVM on black EPDM and with aluminized protective coatings commonly used in conjunction with modified bituminous membranes.
- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric) per the manufacturer’s specifications, taking care not to damage the waterproofing. Any damage occurring must be reported immediately. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.

- The growing media should be mixed prior to delivery to the site. Media must be spread evenly over the filter fabric surface as required by the manufacturer. If a delay between the installation of the growing media and the plants is required, adequate efforts must be taken to secure the growing media from erosion and the seeding of weeds. The growing media must be covered and anchored in place until planting. 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 beyond manufacturer's recommendations.
- 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.
- It generally takes 2 to 3 growing seasons to fully establish the vegetated roof. The growing medium should contain enough organic matter to support plants for the first growing season, so initial fertilization is not required. Extensive green roofs may require supplemental irrigation during the first few months of establishment. Hand weeding is also critical in the first two years (see Table 10.1 of Weiler and Scholz-Barth (2009) for a photo guide of common rooftop weeds).
- Most construction contracts should contain a Care and Replacement Warranty that specifies at least 50 percent coverage after one year and 80 percent coverage after two years for plugs and cuttings, and 90 percent coverage after one year for *Sedum* carpet/tile.

Construction Supervision. Supervision during construction is recommended to ensure that the vegetated roof is built in accordance with these specifications. Inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction and confirm that the contractor's interpretation of the plan is consistent with the intent of the designer and/or manufacturer.

An experienced installer should be retained to construct the vegetated roof system. The vegetated roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Careful construction supervision/inspection is needed throughout the installation of a vegetated roof, as follows:

- During placement of the waterproofing layer, to ensure that it is properly installed and watertight.
- During placement of the drainage layer and drainage system.
- During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth (certification for vendor or source should be provided).
- Upon installation of plants, to ensure they conform to the planting plan (certification from vendor or source should be provided).
- Before issuing use and occupancy approvals.
- At the end of the first or second growing season to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved.

DDOE's construction phase inspection checklist for green roof practices can be found in Appendix K.

3.2.7 Green Roof Maintenance Criteria

Maintenance Inspections. A green roof should be inspected by a qualified professional 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 3.3). In addition, the green roof should be hand weeded to remove invasive or volunteer plants, and plants and/or media should be added to repair bare areas (refer to ASTM E2400 (ASTM, 2006)).

If a roof leak is suspected, it is advisable to perform an electric leak survey (e.g., EVFM), if applicable, 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 some waterproofing membranes. Check with the membrane manufacturer for approval and warranty information. Also, power washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the green roof plant communities.

Fertilization is generally not recommended due to the potential for leaching of nutrients from the green roof. Supplemental fertilization may be required following the first growing season, but only if plants show signs of nutrient deficiencies and a media test indicates a specific deficiency. Addressing this issue with the holder of the vegetation warranty is recommended. If fertilizer is to be applied, it must be a slow-release type, rather than liquid or gaseous form.

DDOE's maintenance inspection checklist for green roofs and the Maintenance Service Completion Inspection form can be found in Appendix L.

Table 3.3 Typical Maintenance Activities Associated with Green Roofs

Schedule (following construction)	**Activity**
As needed or as required by manufacturer	▪ Water to promote plant growth and survival. ▪ Inspect the green roof and replace any dead or dying vegetation.
Semi-annually	▪ Inspect the waterproof membrane for leaks and cracks. ▪ Weed to remove invasive plants (do not dig or use pointed tools where there is potential to harm the root barrier or waterproof membrane). ▪ Inspect roof drains, scuppers, and gutters to ensure they are not overgrown and have not accumulated organic matter deposits. Remove any accumulated organic matter or debris. ▪ Inspect the green roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit Cof the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Materials. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.2.8 Green Roof Stormwater Compliance Calculations

Green roofs receive 100 percent retention value for the amount of storage volume (Sv) provided by the practice (see Table 3.4). Since the practice gets 100 percent retention value, it is not considered an accepted total suspended solids (TSS) treatment practice.

Table 3.4 Green Roof Design Performance

Retention Value	= *Sv*
Accepted TSS Treatment Practice	N/A

The practice must be designed using the guidance detailed in Section 3.2.4.

Green roofs also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the Sv from the total runoff volume for the 2-year, 15-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a Reduced Natural Resource Conservation Service Curve Number for the site or drainage area. The Reduced Curve Number can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

3.2.9 References

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.

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Snodgrass, E. and L. Snodgrass. 2006. Green Roof Plants: a resource and planting guide. Timber Press. Portland, OR.

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Virginia DCR Stormwater Design Specification No. 5: Vegetated Roof Version 2.2. 2010.

3.3 Rainwater Harvesting

Definition. Rainwater harvesting systems store rainfall and release it for future use. Rainwater that falls on a rooftop or other impervious surface is collected and conveyed into an above- or below-ground tank (also referred to as a cistern), where it is stored for non-potable uses or for on-site disposal or infiltration as stormwater. Cisterns can be sized for commercial as well as residential purposes. Residential cisterns are commonly called rain barrels.

Non-potable uses of harvested rainwater may include the following:

- Landscape irrigation,
- Exterior washing (e.g., car washes, building facades, sidewalks, street sweepers, and fire trucks),
- Flushing of toilets and urinals,
- Fire suppression (i.e., sprinkler systems),
- Supply for cooling towers, evaporative coolers, fluid coolers, and chillers,
- Supplemental water for closed loop systems and steam boilers,
- Replenishment of water features and water fountains,
- Distribution to a green wall or living wall system,
- Laundry, and
- Delayed discharge to the combined sewer system.

In many instances, rainwater harvesting can be combined with a secondary (down-gradient) stormwater practice to enhance stormwater retention and/or provide treatment of overflow from the rainwater harvesting system. Some candidate secondary practices include the following:

- Disconnection to a pervious area (compacted cover) or conservation area (natural cover) or soil amended filter path (see Section 3.4 Impervious Surface Disconnection)
- Overflow to bioretention practices (see Section 3.6 Bioretention)
- Overflow to infiltration practices (see Section 3.8 Stormwater Infiltration)
- Overflow to grass channels or dry swales (see Section 3.12 Storage Practices)

By providing a reliable and renewable source of water to end users, rainwater harvesting systems can also have environmental and economic benefits beyond stormwater management (e.g., increased water conservation, water supply during drought and mandatory municipal water supply restrictions, decreased demand on municipal water supply, decreased water costs for the end user, and potential for increased groundwater recharge).

The seven primary components of a rainwater harvesting system are discussed in detail in Section 3.3.4. Some are depicted in Figure 3.2. The components include the following:

- Contributing drainage area (CDA) surface,
- Collection and conveyance system (e.g., gutter and downspouts) (number 1 in Figure 3.2)
- Pretreatment, including prescreening and first flush diverters (number 2 in Figure 3.2)
- Cistern (no number, but depicted in Figure 3.2)
- Water quality treatment (as required by Tiered Risk Assessment Management (TRAM))
- Distribution system
- Overflow, filter path or secondary stormwater retention practice (number 8 in Figure 3.2)

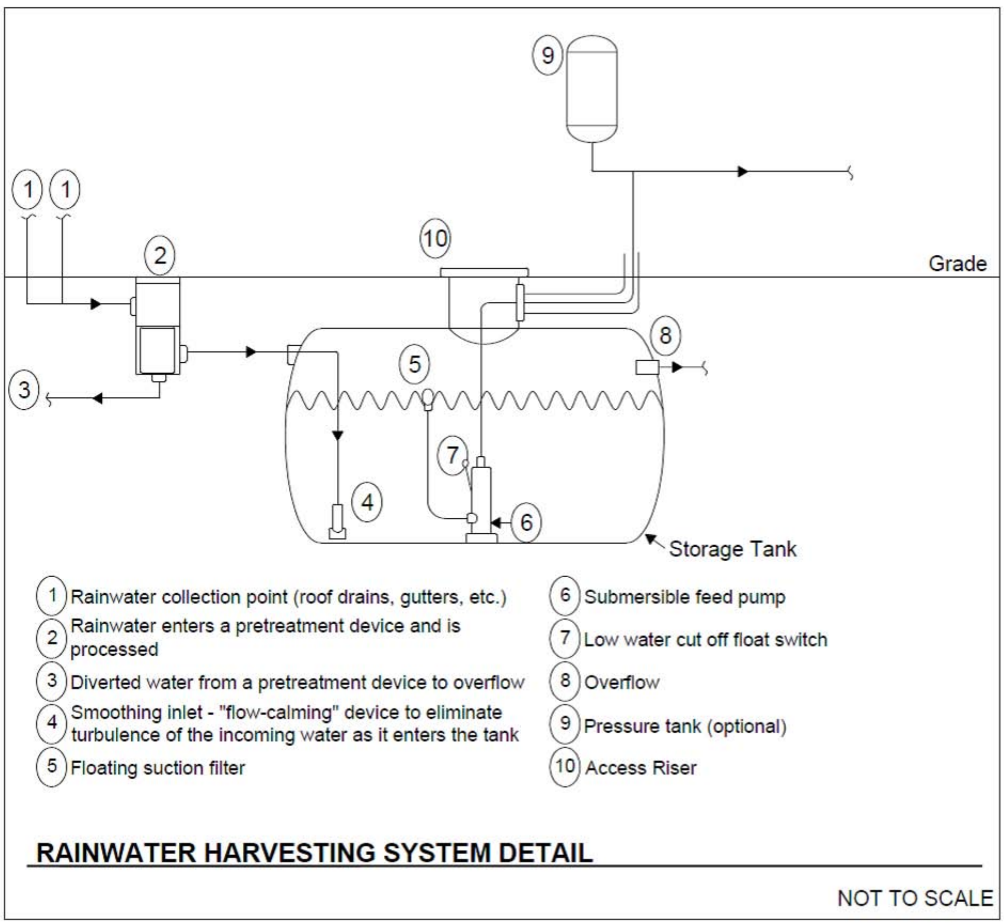

Figure 3.2 Example of a rainwater harvesting system detail.

3.3.1 Rainwater Harvesting Feasibility Criteria

A number of site-specific features influence how rainwater harvesting systems are designed and/or utilized. The following are key considerations for rainwater harvesting feasibility. They are not comprehensive or conclusive; rather, they are recommendations to consider during the planning process to incorporate rainwater harvesting systems into the site design.

Plumbing Code. This specification does not address indoor plumbing or disinfection issues. Designers and plan reviewers should consult the District's construction codes (DCMR, Title 12) to determine the allowable indoor uses and required treatment for harvested rainwater. In cases where a municipal backup supply is used, rainwater harvesting systems must have backflow preventers or air gaps to keep harvested water separate from the main water supply. Distribution and waste pipes, internal to the building, must be stamped non-potable and colored purple consistent with the District's building codes. Pipes and spigots using rainwater must be clearly labeled as non-potable with an accompanying pictograph sign.

Mechanical, Electrical, Plumbing (MEP). For systems that call for indoor use of harvested rainwater, the seal of an MEP engineer is required.

Water Use. When rainwater harvesting will be used, a TRAM (see Appendix M) must be completed and the appropriate form submitted to DDOE. This will outline the design assumptions, outline water quality risks and provide water quality end use standards.

Available Space. Adequate space is needed to house the cistern 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. Cisterns can be placed underground, indoors, adjacent to buildings, and on rooftops that are structurally designed to support the added weight. Designers can work with architects and landscape architects to creatively site the cisterns. Underground utilities or other obstructions should always be identified prior to final determination of the cistern location.

Site Topography. Site topography and cistern location should be considered as they relate to all of the inlet and outlet invert elevations in the rainwater harvesting system.

The final invert of the cistern outlet pipe at the discharge point must match the invert of the receiving mechanism (e.g., natural channel, storm drain system) and be sufficiently sloped to adequately convey this overflow. The elevation drops associated with the various components of a rainwater harvesting system and the resulting invert elevations should be considered early in the design, in order to ensure that the rainwater harvesting system is feasible for the particular site.

Site topography and cistern location will also affect pumping requirements. Locating cisterns in low areas will make it easier to get water into the cisterns; however, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigated areas situated on higher ground. Conversely, placing cisterns at higher elevations may require larger diameter pipes with smaller slopes but will generally reduce the amount of pumping needed for distribution. It is often best to locate a cistern close to the building or drainage area, to limit the amount of pipe needed.

Available Hydraulic Head. The required hydraulic head depends on the intended use of the water. For residential landscaping uses, the cistern may be sited up-gradient of the landscaping areas or on a raised stand. Pumps are commonly used to convey stored rainwater to the end use in order to provide the required head. When the water is being routed from the cistern to the inside of a building for non-potable use, often a pump is used to feed a much smaller pressure tank inside the building, which then serves the internal water demands. Cisterns can also use gravity to accomplish indoor residential uses (e.g., laundry) that do not require high water pressure.

Water Table. Underground storage tanks are most appropriate in areas where the tank can be buried above the water table. The tank should be located in a manner that is not subject it to flooding. In areas where the tank is to be buried partially below the water table, special design features must be employed, such as sufficiently securing the tank (to keep it from floating), and conducting buoyancy calculations when the tank is empty. The tank may need to be secured appropriately with fasteners or weighted to avoid uplift buoyancy. The combined weight of the tank and hold-down ballast must meet or exceed the buoyancy force of the cistern. The cistern must also be installed according to the cistern manufacturer’s specifications.

Soils. Cisterns should only be placed on native soils or on fill in accordance with the manufacturer's guidelines. The bearing capacity of the soil upon which the cistern will be placed must be considered, as full cisterns can be very heavy. This is particularly important for above-ground cisterns, as significant settling could cause the cistern to lean or in some cases to potentially topple. A sufficient aggregate, or concrete foundation, may be appropriate depending on the soils and cistern characteristics. Where the installation requires a foundation, the foundation must be designed to support the cistern’s weight when the cistern is full consistent with the bearing capacity of the soil and good engineering practice. The pH of the soil should also be considered in relation to its interaction with the cistern material.

Proximity of Underground Utilities. All underground utilities must be taken into consideration during the design of underground rainwater harvesting systems, treating all of the rainwater harvesting system components and storm drains as typical stormwater facilities and pipes. The underground utilities must be marked and avoided during the installation of underground cisterns and piping associated with the system.

Contributing Drainage Area. The contributing drainage area (CDA) to the cistern is the impervious area draining to the cistern. Rooftop surfaces are what typically make up the CDA, but paved areas can be used with appropriate treatment (oil/water separators and/or debris excluders). 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 the drainage area 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.

Contributing Drainage Area Material. The quality of the harvested rainwater will vary according to the roof material or drainage area over which it flows. Water harvested from certain types of rooftops and CDAs, such as asphalt sealcoats, tar and gravel, painted roofs, galvanized metal roofs, sheet metal, or any material that may contain asbestos may leach trace metals and other toxic compounds. In general, harvesting rainwater from such surfaces should be avoided. If harvesting from a sealed or painted roof surface is desired, it is recommended that the sealant or paint be certified for such purposes by the National Sanitation Foundation (ANSI/NSF standard).

Water Quality of Rainwater. Designers should also note that the pH of rainfall in the District tends to be acidic (ranging from 4.5 to 5.0), which may result in leaching of metals from roof surfaces, cistern lining or water laterals, to interior connections. Once rainfall leaves rooftop surfaces, pH levels tend to be slightly higher, ranging from 5.5 to 6.0. Limestone or other materials may be added in the cistern to buffer acidity, if desired.

Hotspot Land Uses. Harvesting rainwater can be an effective method to prevent contamination of rooftop runoff that would result from mixing it with ground-level runoff from a stormwater hotspot operation.

Setbacks from Buildings. Cistern overflow devices must be designed to avoid causing ponding or soil saturation within 10 feet of building foundations. While most systems are generally sited underground and more than ten feet laterally from the building foundation wall, some cisterns are incorporated into the basement of a building or underground parking areas. In any case, cisterns must be designed to be watertight to prevent water damage when placed near building foundations.

Vehicle Loading. Whenever possible, underground rainwater harvesting systems should be placed in areas without vehicle traffic or other heavy loading, such as deep earth fill. If site constraints dictate otherwise, systems must be designed to support the loads to which they will be subjected.

3.3.2 Rainwater Harvesting Conveyance Criteria

Collection and Conveyance. The collection and conveyance system consists of the gutters, downspouts, and pipes that channel rainfall into cisterns. Gutters and downspouts should be designed as they would for a building without a rainwater harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for rainwater harvesting. Typically, gutters should be hung at a minimum of 0.5 percent for 2/3 of the length and at 1 percent for the remaining 1/3 of the length in order to adequately convey the design storm (i.e.., Stormwater Retention Volume (SWRv)). If the system will be used for management of the 2-year and 15-year storms, the gutters must be designed to convey the appropriate 2-year and 15-year storm intensities.

Pipes, which connect downspouts to the cistern, should be at a minimum slope of 1.5 percent and sized/designed to convey the intended design storm, as specified above. In some cases, a steeper slope and larger sizes may be recommended and/or necessary to convey the required runoff, depending on the design objective and design storm intensity. Gutters and downspouts should be kept clean and free of debris and rust.

Overflow. An overflow mechanism must be included in the rainwater harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the cistern. Overflow pipe(s) must have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe(s) must be screened to prevent access to the cistern by small mammals and birds. All overflow from the system must be directed to an acceptable flow path that will not cause erosion during a 2-year storm event.

3.3.3 Rainwater Harvesting Pretreatment Criteria

Prefiltration is required to keep sediment, leaves, contaminants, and other debris from the system. Leaf screens and gutter guards meet the minimal requirement for prefiltration of small systems, although direct water filtration is preferred. The purpose of prefiltration is to significantly cut down on maintenance by preventing organic buildup in the cistern, thereby decreasing microbial food sources.

Diverted flows (i.e., first flush diversion and/or overflow from the filter, if applicable) must be directed to an appropriate BMP or to a settling tank to remove sediment and pollutants prior to discharge from the site.

Various pretreatment devices are described below. In addition to the initial first flush diversion, filters have an associated efficiency curve that estimates the percentage of rooftop runoff that will be conveyed through the filter to the cistern. If filters are not sized properly, a large portion of the rooftop runoff may be diverted and not conveyed to the cistern at all. A design intensity of 1 inch/hour (for design storm = SWRv) must be used for the purposes of sizing pre-cistern conveyance and filter components. This design intensity captures a significant portion of the total rainfall during a large majority of rainfall events (NOAA, 2004). If the system will be used for channel and flood protection, the 2-year and 15-year storm intensities must be used for the design of the conveyance and pretreatment portion of the system. The Rainwater Harvesting Retention Calculator, discussed more in Section 3.3.4, allows for input of variable filter efficiency rates for the SWRv design storm. To meet the requirements to manage the 2-year and 15-year storms, a minimum filter efficiency of 90 percent must be met.

- **First Flush Diverters.** First flush diverters (see Figure 3.3) direct the initial pulse of rainfall away from thecistern. While leaf screens effectively remove larger debris such as leaves, twigs, and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen, and bird and rodent feces.
- **Leaf Screens.** Leaf screens are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into thecisterns. Built-up debris can also harbor bacterial growth within gutters or downspouts (Texas Water Development Board, 2005).
- **Roof Washers.** Roof washers are placed just ahead of cisterns and are used to filter small debris from harvested rainwater (see Figure 3.4). Roof washers consist of a cistern, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30 microns. The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.
- **Hydrodynamic Separator.** For large-scale applications, hydrodynamic separators and other devices can be used to filter rainwater from larger CDAs.

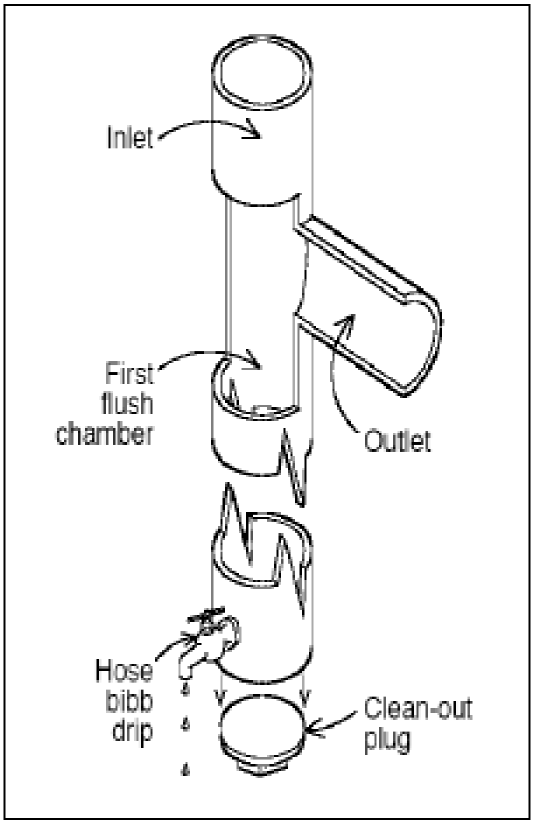

Figure 3.3 Diagram of a first flush diverter. (Texas Water Development Board, 2005)

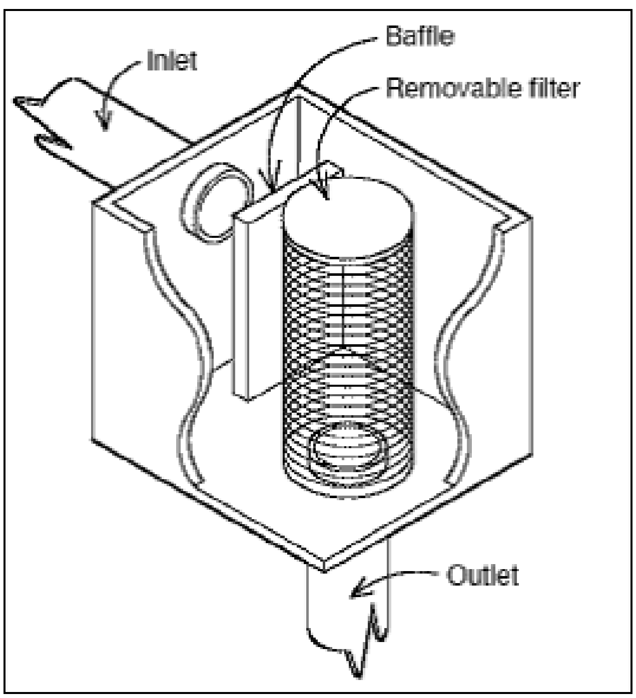

Figure 3.4 Diagram of a roof washer. (Texas Water Development Board, 2005)

3.3.4 Rainwater Harvesting Design Criteria

System Components: Seven primary components of a rainwater harvesting system require special considerations (some of these are depicted in Figure 3.2):

- CDA or CDA surface
- Collection and conveyance system (i.e., gutter and downspouts)
- Cisterns
- Pretreatment, including prescreening and first flush diverters
- Water quality treatment (as required by TRAM)
- Distribution systems
- Overflow, filter path or secondary stormwater retention practice

The system components are discussed below:

- **CDA Surface.** When considering CDA surfaces, note smooth, non-porous materials will drain more efficiently. Slow drainage of the CDA leads to poor rinsing and a prolonged first flush, which can decrease water quality. If the harvested rainwater will be directed towards uses with significant human exposure (e.g., pool filling, public sprinkler fountain), care should be taken in the choice of CDA materials. Some materials may leach toxic chemicals making the water unsafe for humans. In all cases, follow the advice of the TRAM found in Appendix M.

  Rainwater can also be harvested from other impervious surfaces, such as parking lots and driveways; however, this practice requires more extensive pretreatment and treatment prior to reuse.
- **Collection and Conveyance System.** See Section 3.3.2 Rainwater Harvesting Conveyance Criteria.
- **Pretreatment.** See Section 3.3.3 Rainwater Harvesting Pretreatment Criteria.
- **Cisterns.** The cistern is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities generally range from 250 to 30,000 gallons, but they can be as large as 100,000 gallons or more for larger projects. Multiple cisterns can be placed adjacent to each other and connected with pipes to balance water levels and to tailor the storage volume needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Cistern volumes are calculated to meet the water demand and stormwater storage volume retention objectives, as described further below in this specification.

  While many of the graphics and photos in this specification depict cisterns with a cylindrical shape, the cisterns can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the cisterns will be installed. For example, configurations can be rectangular, L-shaped, or step vertically to match the topography of a site. The following factors should be considered when designing a rainwater harvesting system and selecting a cistern:

- Aboveground cisterns should be ultraviolet and impact resistant.
- Underground cisterns must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic).
- Underground rainwater harvesting systems must have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. The access opening must be installed in such a way as to prevent surface- or groundwater from entering through the top of any fittings, and it must be secured/locked to prevent unwanted entry. Confined space safety precautions/requirements should be observed during cleaning, inspection, and maintenance.
- All rainwater harvesting systems must be sealed using a water-safe, non-toxic substance.
- Rainwater harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. Table 3.5 below compares the advantages and disadvantages of different cistern materials.
- Cisterns must be opaque or otherwise protected from direct sunlight to inhibit growth of algae, and they must be screened to discourage mosquito breeding.
- Dead storage below the outlet to the distribution system and an air gap at the top of the cistern must be included in the total cistern volume. For gravity-fed systems, a minimum of 6 inches of dead storage must be provided. For systems using a pump, the dead storage depth will be based on the pump specifications.
- Any hookup to a municipal backup water supply must have a backflow prevention device to keep municipal water separate from stored rainwater; this may include incorporating an air gap to separate the two supplies.

Table 3.5 Advantages and Disadvantages of Typical Cistern Materials (Source: Cabell Brand Center, 2007; Cabell Brand Center, 2009)

Cistern 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 watertight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (20 to 50 gallons); limited application
Galvanized Steel	Commercially available, alterable, and moveable; available in a range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; must be lined for potable use; can only install above ground; soil pH may limit underground applications

Cistern Material	Advantages	Disadvantages
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, and 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

- **Water Quality Treatment.** Depending upon the collection surface, method of dispersal, and proposed use for the harvested rainwater, a water quality treatment device may be required by the TRAM (see Appendix M).
- **Distribution Systems.** Most distribution systems require a pump to convey harvested rainwater from the cistern to its final destination, whether inside the building, an automated irrigation system, or gradually discharged to a secondary stormwater treatment practice. The rainwater harvesting system should be equipped with an appropriately sized pump that produces sufficient pressure for all end-uses.

  The typical pump and pressure tank arrangement consists of a multi-stage, centrifugal pump, which draws water out of the cistern and sends it into the pressure tank, where it is stored for distribution. Some systems will not require this two-tank arrangement (e.g., low-pressure and gravel systems). When water is drawn out of the pressure tank, the pump activates to supply additional water to the distribution system. The backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.

  Distribution lines from the rainwater harvesting system should be buried beneath the frost line. Lines from the rainwater harvesting system to the building should have shut-off valves that are accessible when snow cover is present. A drain plug or cleanout sump must be installed to allow the system to be completely emptied, if needed. Above-ground outdoor pipes must be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter if winter use is planned.
- **Overflow.** See Section 3.3.2 Rainwater Harvesting Conveyance Criteria.

Rainwater Harvesting Material Specifications. The basic material specifications for rainwater harvesting systems are presented in Table 3.6. Designers should consult with experienced rainwater harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated cisterns and other system components.

Table 3.6 Design Specifications for Rainwater Harvesting Systems

Item	Specification
Gutters and Downspouts	Materials commonly used for gutters and downspouts include polyvinylchloride (PVC) pipe, vinyl, aluminum, and galvanized steel. Lead must 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 cisterns. ▪ Be sure to include needed bends and tees.
Pretreatment	At least one of the following (all rainwater to pass through pretreatment): ▪ First flush diverter ▪ Hydrodynamic separator ▪ Roof washer ▪ Leaf and mosquito screen (1 mm mesh size)
Cisterns	▪ Materials used to construct cisterns must be structurally sound. ▪ Cisterns should be constructed in areas of the site where soils can support the load associated with stored water. ▪ Cisterns must be watertight and sealed using a water-safe, non-toxic substance. ▪ Cisterns must be opaque or otherwise shielded to prevent the growth of algae. ▪ The size of the rainwater harvesting system(s) is determined through design calculations.

Note: This table does not address indoor systems or pumps.

Design Objectives and System Configuration. Rainwater harvesting systems can have many design variations that meet user demand and stormwater objectives. This specification provides a design framework to achieve the SWRv objectives that are required to comply with the regulations, and it adheres to the following concepts:

- Give preference to use of rainwater as a resource to meet on-site demand or in conjunction with other stormwater retention practices.
- Reduce peak flow by achieving volume reduction and temporary storage of runoff.

Based on these concepts, this specification focuses on system design configurations that harvest rainwater for internal building uses, seasonal irrigation, and other activities, such as cooling tower use and vehicle washing. While harvested rainwater will be in year-round demand for many internal building uses, some other uses will have varied demand depending on the time of year (e.g., cooling towers and seasonal irrigation). Thus, a lower retention value is assigned to a type of use that has reduced demand.

Design Objectives and Cistern Design Set-Ups. Prefabricated rainwater harvesting cisterns typically range in size from 250 to over 30,000 gallons. Three basic cistern designs meet the various rainwater harvesting system configurations in this section.

- **Cistern Design 1.** The first cistern set-up (Figure 3.5) maximizes the available storage volume associated with the SWRv to meet the desired level of stormwater retention. This layout also maximizes the storage that can be used to meet a demand. An emergency overflow exists near the top of the cistern as the only gravity release outlet device (not including the pump, manway, or inlets). It should be noted that it is possible to address 2-year and 15-year storm volumes with this cistern configuration, but the primary purpose is to address the smaller SWRv design storm.

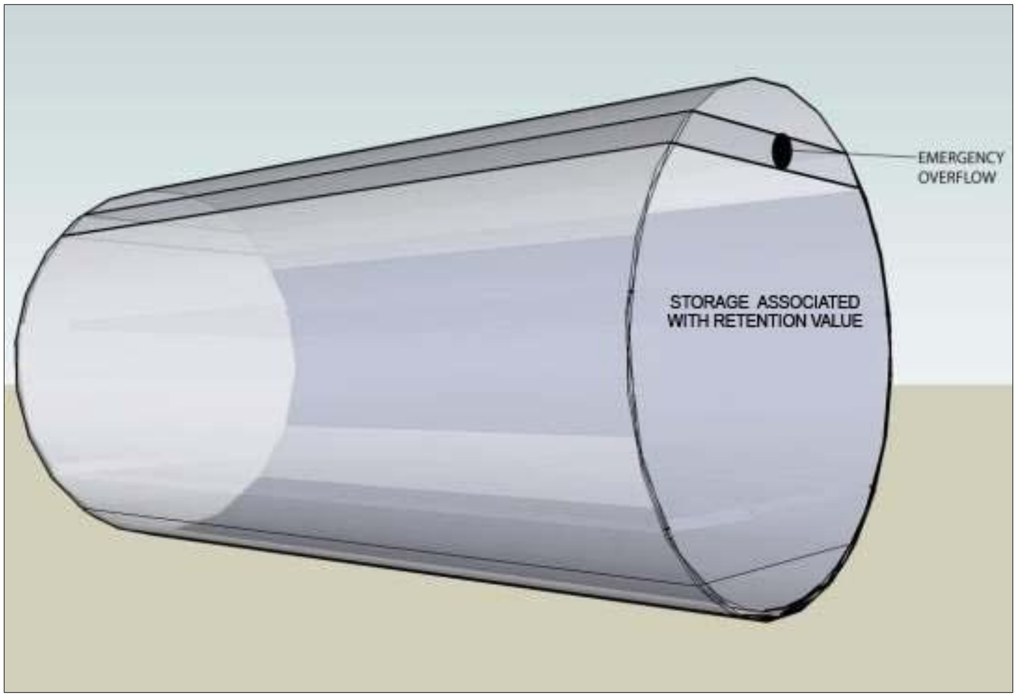

Figure 3.5 Cistern Design 1: Storage associated with the design storm volume only.

- **Cistern Design 2.** The second cistern set-up (Figure 3.6) uses cistern storage to meet the SWRv storage objectives and also uses additional detention volume to meet some or all of the 2-year and 15-year storm volume requirements. An orifice outlet is provided at the top of the design storage for the SWRv level, and an emergency overflow is located at the top of the detention volume level.

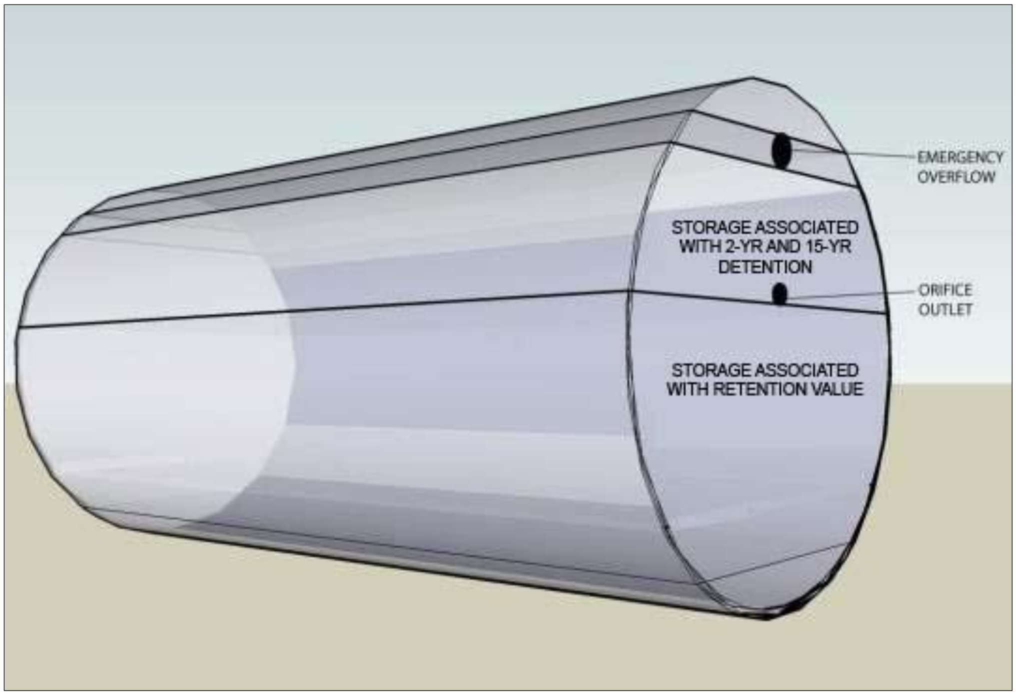

Figure 3.6 Cistern Design 2: Storage associated with design storm, channel protection, and flood volume.

- **Cistern Design 3.** The third cistern set-up (Figure 3.7) creates a constant drawdown within the system. The small orifice at the bottom of the cistern needs to be routed to an appropriately designed secondary practice (i.e., bioretention, stormwater infiltration) that will allow the rainwater to be treated and allow for groundwater recharge over time. The release must not be discharged to a receiving channel or storm drain without treatment, and maximum specified drawdown rates from this constant drawdown should be adhered to, since the primary function of the system is not intended to be detention.

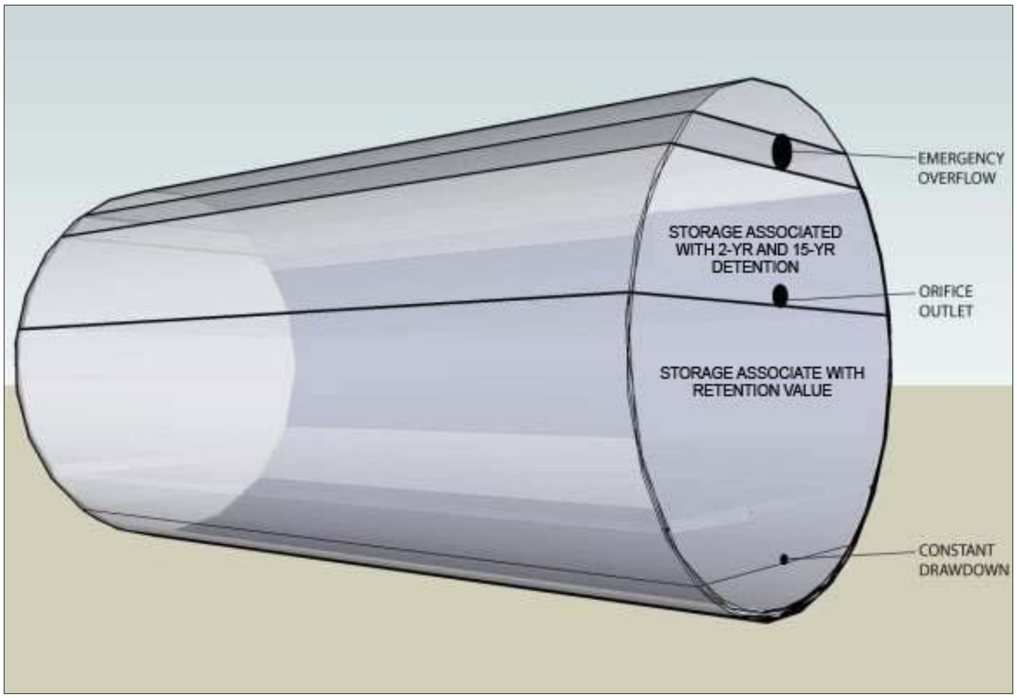

Figure 3.7 Cistern Design 3: Constant drawdown version where storage is associated with design storm, channel protection, and flood volume.

Design Storm, Channel Protection, and Flood Volume. For the purposes of the third cistern design, the secondary practice must be considered a component of the rainwater harvesting system with regard to the storage volume percentage calculated in the General Retention Compliance Calculator (discussed in Chapter 5 and Appendix A). In other words, the storage volume associated with the secondary practice must not be added (or double-counted) to the rainwater harvesting percentage because the secondary practice is an integral part of a rainwater harvesting system with a constant drawdown. The exception to this requirement would be if the secondary practice were also sized to capture and treat impervious and/or turf area beyond the area treated by rainwater harvesting (for example from the adjacent yard or a driveway). In this case, only these additional areas should be added into the General Retention Compliance Calculator to receive retention volume achieved for the secondary practice.

While a small orifice is shown at the bottom of the cistern in Figure 3.7, the orifice could be replaced with a pump that would serve the same purpose, conveying a limited amount of water to a secondary practice on a routine basis.

Sizing of Rainwater Harvesting Systems. The rainwater harvesting cistern sizing criteria presented in this section were developed using a spreadsheet model that used best estimates of indoor and outdoor water demand, long-term rainfall data, and CDA capture area data (Forasté2011). The Rainwater Harvesting Retention Calculator is for cistern sizing guidance and to quantify the retention value for storage volume achieved. This retention value is required for input into the General Retention Compliance Calculator and is part of the submission of a Stormwater Management Plan (SWMP) using rainwater harvesting systems for compliance. A secondary objective of the spreadsheet is to increase the beneficial uses of the stored stormwater, treating it as a valuable natural resource. More information on the Rainwater Harvesting Retention Calculator can be found later in this section. The spreadsheet can be found on DDOE's website at http://ddoe.dc.gov/swregs.

Rainwater Harvesting Retention Calculator. The design specification provided in this section (Rainwater Harvesting) is linked with the Rainwater Harvesting Retention Calculator. The spreadsheet uses daily rainfall data from September 1, 1977 to September 30, 2007 to model performance parameters of the cistern under varying CDAs, demands on the system, and cistern size.

The runoff that reaches the cistern each day is added to the water level that existed in the cistern the previous day, with all of the total demands subtracted on a daily basis. If any overflow is realized, the volume is quantified and recorded. If the cistern runs dry (reaches the cut-off volume level), then the volume in the cistern is fixed at the low level, and a dry-frequency day is recorded. The full or partial demand met in both cases is quantified and recorded. A summary of the water balance for the system is provided below.

Incremental Design Volumes within Cistern. Rainwater cistern sizing is determined by accounting for varying precipitation levels, captured CDA runoff, first flush diversion (through filters) and filter efficiency, low water cut-off volume, dynamic water levels at the beginning of various storms, storage needed for the design storm (permanent storage), storage needed for 2-year or 15-year volume (temporary detention storage), seasonal and year-round demand use and objectives, overflow volume, and freeboard volumes above high water levels during very large storms. See Figure 3.8 for a graphical representation of these various incremental design volumes.

The design specification described in this section (Rainwater Harvesting) does not provide guidance for sizing larger storms (e.g., Qp_2, Qp_{15}, and Q_f), but rather provides guidance on sizing for the SWRv design storms.

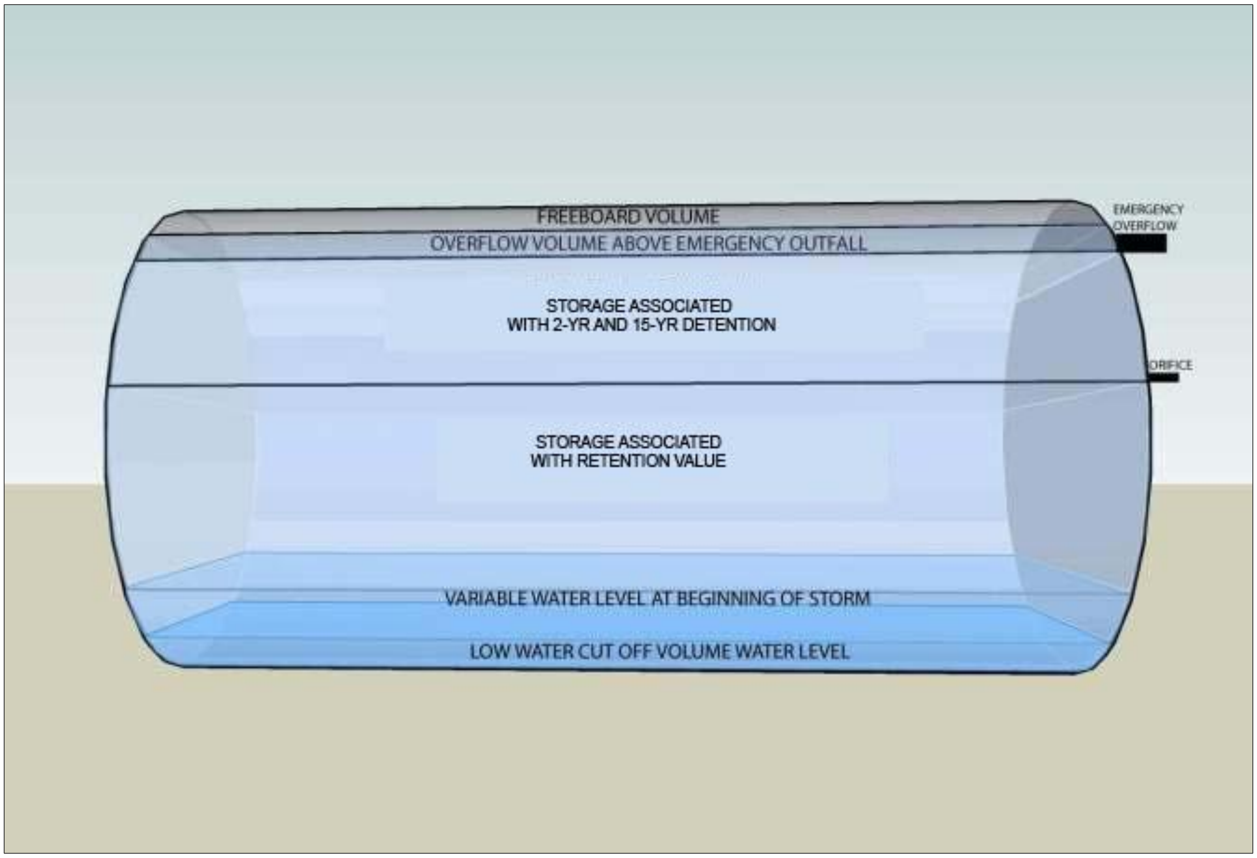

Figure 3.8 Incremental design volumes associated with cistern sizing.

The “Storage Associated with the Retention Value” is the storage within the cistern that is modeled and available for reuse. While the SWRv will remain the same for a specific CDA, the “Storage Associated with the Retention Value” may vary depending on demand and storage volume retention objectives. It includes the variable water level at the beginning of a storm and the low water cut-off volume that is necessary to satisfy pumping requirements.

Water Contribution

- **Precipitation.** The volume of water contributing to the rainwater harvesting system is a function of the rainfall andCDA, as defined by the designer.
- **Municipal Backup (optional).** In some cases, the designer may choose to install a municipal backup water supply to supplement cistern levels. Note that municipal backups may also be connected post-cistern (i.e., a connection is made to the non-potable water line that is used for pumping water from the cistern for reuse), thereby not contributing any additional volume to the cistern. Municipal backup designs that supply water directly to the cistern are not accounted for in the Rainwater Harvesting Retention Calculator.

Water Losses

- **Drainage Area Runoff Coefficient.** The CDA is assumed to convey 95 percent of the rainfall that lands on its surface (i.e., Rv = 0.95).
- **First Flush Diversion.** The first 0.02 to 0.06 inches of rainfall that is directed to filters is diverted from the system in order to prevent clogging it with debris. This value is assumed to be contained within the filter efficiency rate.
- **Filter Efficiency.** It is assumed that, after the first flush diversion and loss of water due to filter inefficiencies, the remainder of the SWRv storm will be successfully captured. For the 1.2-inch storm, a minimum of 95 percent of the runoff should be conveyed into the cistern. For the 3.2-inch storm, a minimum of 90 percent of the runoff should be conveyed. These minimum values are included as the filter efficiencies in the Rainwater Harvesting Retention Calculator, although they can be altered (increased) if appropriate. The Rainwater Harvesting Retention Calculator applies these filter efficiencies, or interpolated values, to the daily rainfall record to determine the volume of runoff that reaches the cistern. For the purposes of selecting an appropriately sized filter, a rainfall intensity of 1 inch per hour shall be used for the SWRv. The appropriate rainfall intensity values for the 2-year (3.2-inch) and 15-year storms shall be used when designing for larger storm events.
- **Drawdown (Storage Volume).** This is the stored water within the cistern that is reused or directed to a secondary stormwater practice. It is the volume of runoff that is reduced from the CDA. This is the water loss that translates into the achievable storage volume retention.
- **Overflow.** For the purposes of addressing the SWRv (not for addressing larger storm volumes), orifice outlets for both detention and emergency overflows are treated the same. This is the volume of water that may be lost during large storm events or successive precipitation events.

Results for all Precipitation Events. The performance results of the rainwater harvesting system for all days during the entire period modeled, including the full spectrum of precipitation events, is included in the "Results" tab. This tab is not associated with determining the storage volume achieved, but instead may be a useful tool in assisting the user to realize the performance of the various rainwater harvesting system sizes with the design parameters and demands specified.

- **Percentage of Demand Met.** This is where the percentage of demand met for various size cisterns and CDA/demand scenarios is reported. A graph displaying the percentage of demand met versus the percentage of overflow frequency for various cistern sizes is provided in this tab. Normally, this graph assists the user in understanding the relationship between cistern sizes and optimal/diminishing returns. An example is provided below in Figure 3.9.

  At some point, larger cisterns no longer provide significant increases in percentages of demand met. Conversely, the curve informs the user when a small increase in cistern size can yield a significant increase in the percentage of time that demand is met.

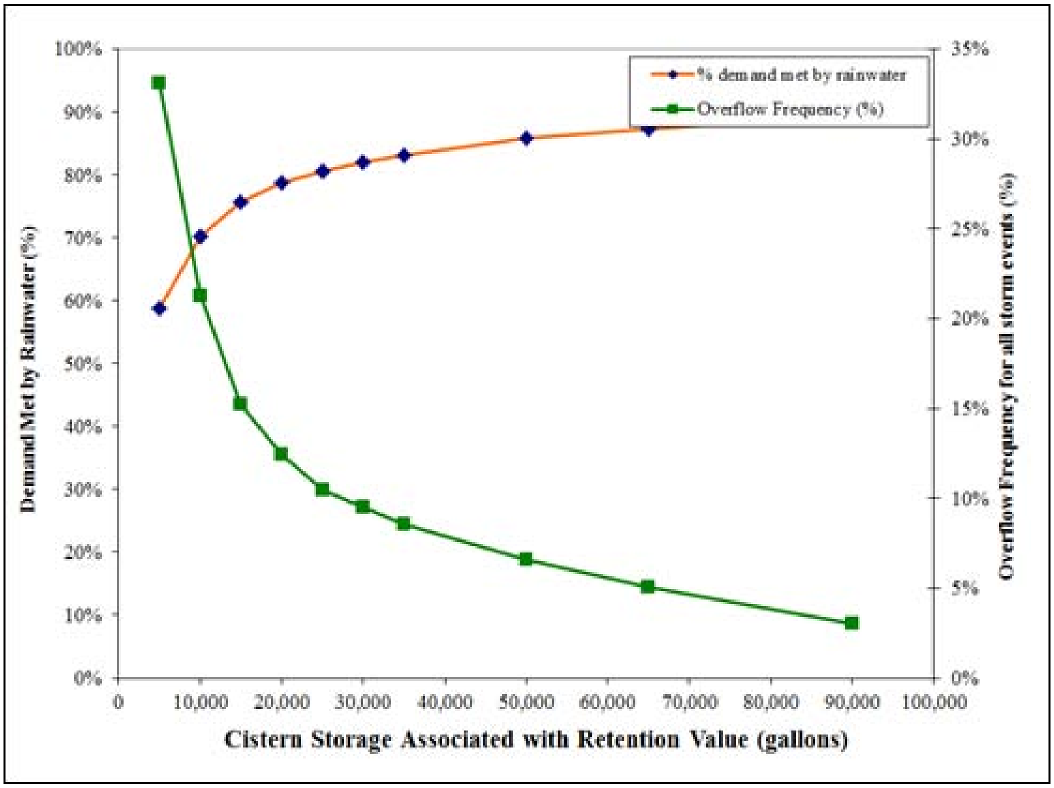

Figure 3.9 Example of percent demand met versus cistern storage.

- **Dry Frequency.** Another useful measure is the dry frequency. If the cistern is dry a substantial portion of the time, this measure can inform the user that he/she may want to decrease the size of the cistern, decrease the demand on the system, or explore capturing more CDA to provide a larger supply, if feasible. It can also provide useful insight for the designer to determine whether he/she should incorporate a municipal backup supply to ensure sufficient water supply through the system at all times.
- **Overflow Frequency.** This is a metric of both overflow frequency and average volume per year for the full spectrum of rainfall events. This metric will inform the user regarding the design parameters, magnitude of demand, and associated performance of the system. If the system overflows at a high frequency, then the designer may want to increase the size of the cistern, decrease the CDA captured, or consider other mechanisms that could increase drawdown (e.g., increase the area to be irrigated, incorporate or increase on-site infiltration, etc.).
- **Inter-relationships and Curves of Diminishing Returns.** Plotting various performance metrics against one another can be very informative and reveal relationships that are not evident otherwise. An example of this usefulness is demonstrated when the plot of “percentage-of-demand-met versus cistern size” is compared against the plot of “the percentage-of-overflow-frequency versus cistern size.” By depicting these plots on the same graph, a range of optimum cistern sizes emerges. This informs the designer where a small increase or decrease in cistern size will have a significant impact on dry frequency and overflow frequency. Looking outside this range will indicate where changes in cistern sizes

will not have significant influence over dry frequency and overflow frequency, but may offer a large trade-off compared to the cost of the rainwater harvesting system.

Results for Retention Value. The retention value percentage of CDA runoff volume that the cistern can capture for a 1.7-inch storm on an average daily basis given the water demands by the user is presented on the "Results-Retention Value" tab. This information is used to calculate the retention value percentage, which is used as an input to the General Retention Compliance Calculator.

- **Retention Value Percentage Achieved.** The percentage of retention value achieved is calculated for multiple sizes of cisterns. A trade-off curve plots these results, which allows for a comparison of the retention achieved versus cistern size. While larger cisterns yield more retention, they are more costly. The curve helps the user to choose the appropriate cistern size, based on the design objectives and site needs, and to understand the rate of diminishing returns.
- **Overflow Volume.** The volume of the overflows resulting from a 1.7-inch precipitation event is also reported in this tab. A chart of the retention value and overflow frequency versus the storage volume is provided. An example is shown in Figure 3.10.

  These plotted results establish a trade-off relationship between these two performance metrics. In the example in Figure 3.10, a 13,000 gallon cistern optimizes the storage volume achieved and the overflow frequency (near the inflection point of both curves).

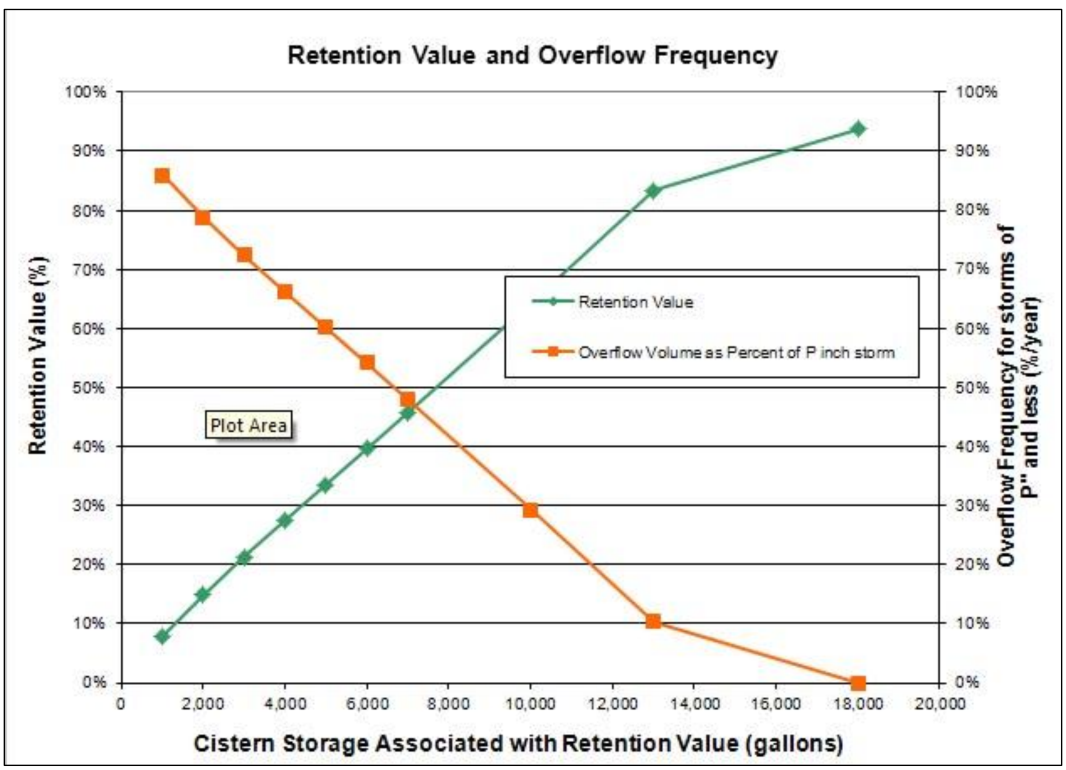

Figure 3.10 Example of retention value percentage achieved versus storage for non-potable uses.

Results from the Rainwater Harvesting Retention Calculator to be Transferred to the General Retention Compliance Calculator. There are two results from the Rainwater Harvesting Retention Calculator that are to be transferred to the General Retention Compliance Calculator, as follows:

- **Contributing Drainage Area (CDA).** Enter the CDA that was used in the Rainwater Harvesting Retention Calculator in the same row into the Drainage Area columns in the blue cell (cell B26-D31).
- **Retention Value.** Once the cistern storage volume associated with the retention value has been selected, transfer that achieved percentage into the General Retention Compliance Calculator column called “% Retention Value” in the “Rainwater Harvesting” row (cell I33).

Completing the Sizing Design of the Cistern. The total size of the cistern is the sum of the following four volume components:

- **Low Water Cutoff Volume (Included).** A dead storage area must be included so the pump will not run the cistern dry. This volume is included in the Rainwater Harvesting Retention Calculator’s modeled volume.
- **Cistern Storage Associated with Design Volume (Included).** This is the design volume from the Rainwater Harvesting Retention Calculator.
- **Adding Channel Protection and Flood Volumes (Optional).** Additional detention volume may be added above and beyond the cistern storage associated with the design storm volumes for the 2-year or 15-year events. Typical routing software programs may be used to design for this additional volume.
- **Adding Overflow and Freeboard Volumes (Required).** An additional volume above the emergency overflow must be provided in order for the cistern to allow very large storms to pass. Above this overflow water level, there will be an associated freeboard volume that should account for at least 5 percent of the overall cistern size. Sufficient freeboard must be verified for large storms, and these volumes must be included in the overall size of the cistern.

3.3.5 Rainwater Harvesting Landscaping Criteria

If the harvested water is to be used for irrigation, the design plan elements must include the proposed delineation of planting areas to be irrigated, the planting plan, and quantification of the expected water demand. The default water demand for irrigation is 1.0 inches per week over the area to be irrigated. Justification must be provided if larger volumes are to be used.

3.3.6 Rainwater Harvesting Construction Sequence

Installation. It is advisable to have a single contractor to install the rainwater harvesting system, outdoor irrigation system, and secondary retention practices. The contractor should be familiar with rainwater harvesting system sizing, installation, and placement. A licensed plumber is required to install the rainwater harvesting system components to the plumbing system.

A standard construction sequence for proper rainwater harvesting system installation is provided below. This can be modified to reflect different rainwater harvesting system applications or expected site conditions.

1. Choose the cistern location on the site
2. Route all downspouts or pipes to prescreening devices and first flush diverters
3. Properly install the cistern
4. Install the pump (if needed) and piping to end uses (indoor, outdoor irrigation, or cistern dewatering release)
5. Route all pipes to the cistern
6. Stormwater must not be diverted to the rainwater harvesting system until the overflow filter path has been stabilized with vegetation.

Construction Supervision. The following items should be inspected by a qualified professional prior to final sign-off and acceptance of a rainwater harvesting system:

- Rooftop area matches plans
- Diversion system is properly sized and installed
- Pretreatment system is installed
- Mosquito screens are installed on all openings
- Overflow device is directed as shown on plans
- Rainwater harvesting system foundation is constructed as shown on plans
- Catchment area and overflow area are stabilized
- Secondary stormwater treatment practice(s) is installed as shown on plans

DDOE's construction phase inspection checklist for rainwater harvesting practices and the Stormwater Facility Leak Test form can be found in Appendix K.

3.3.7 Rainwater Harvesting Maintenance Criteria

Maintenance Inspections. Periodic inspections and maintenance shall be conducted for each system by a qualified professional.

DDOE's maintenance inspection checklists for rainwater harvesting systems and the Maintenance Service Completion Inspection form can be found in Appendix L.

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 3.7 describes routine maintenance tasks necessary to keep rainwater harvesting systems in working condition. Maintenance tasks must be performed by an "Inspector Specialist," certified by the American Rainwater Catchment Association.

Maintenance tasks must be documented and substantially comply with the maintenance responsibilities outlined in the declaration of covenants.

Table 3.7 Typical Maintenance Tasks for Rainwater Harvesting Systems

Responsible Person	Frequency	Activity
Owner	Four times a year	Inspect and clean prescreening devices and first flush diverters
	Twice a year	Keep gutters and downspouts free of leaves and other debris
	Once a year	▪ Inspect and clean storage cistern lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately ▪ Inspect condition of overflow pipes, overflow filter path, and/or secondary stormwater treatment practices
	Every third year	Clear overhanging vegetation and trees over roof surface
Qualified Third Party Inspector	According to Manufacturer	Inspect water quality devices
	As indicated in TRAM	Provide water quality analysis to DDOE
	Every third year	▪ Inspect cistern for sediment buildup ▪ Check integrity of backflow preventer ▪ Inspect structural integrity of cistern, pump, pipe and electrical system ▪ Replace damaged or defective system components

Mosquitoes. In some situations, poorly designed rainwater harvesting systems can create habitat suitable for mosquito breeding. Designers must provide screens on above- and below-ground cisterns to prevent mosquitoes and other insects from entering the cisterns. 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.

Cold Climate Considerations. Rainwater harvesting systems have a number of components that can be impacted by freezing temperatures. Designers should give careful consideration to these conditions to prevent system damage and costly repairs.

For above-ground systems, wintertime operation may be more challenging, depending on cistern size and whether heat tape is used on piping. If not protected from freezing, these rainwater harvesting systems must be taken offline for the winter and stormwater treatment values may not be granted for the practice during that off-line period. At the start of the winter season, vulnerable above-ground systems that have not been designed to incorporate special precautions should be disconnected and drained. It may be possible to reconnect former roof leader systems for the winter.

For underground and indoor systems, downspouts and overflow components should be checked for ice blockages during snowmelt events.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner’s primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit Cof the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.3.8 Rainwater Harvesting: Stormwater Compliance Calculations

Rainwater harvesting practices receive a partial retention value for the SWRv that is equivalent to the percent retention achieved determined by using the Rainwater Harvesting Retention Calculator, as described in Section 3.3.4. Rainwater harvesting is not an accepted total suspended solids treatment practice.

3.3.9 References

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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.

Texas Water Development Board (TWDB). 2005. The Texas Manual on Rainwater Harvesting. Third Ed. Austin, TX.

3.4 Impervious Surface Disconnection

Definition. This strategy involves managing runoff close to its source by intercepting, infiltrating, filtering, treating or reusing it as it moves from an impervious surface to the drainage system. Disconnection practices can be used to reduce the volume of runoff that enters the combined or separate sewer systems. Two kinds of disconnection are allowed: (1) simple disconnection, whereby rooftops and/or on-lot residential impervious surfaces are directed to pervious areas (compacted cover) or conservation areas (natural cover) or soil amended filter paths, and (2) disconnection leading to an alternative retention practice(s) adjacent to the roof (see Figure 3.11). Alternative practices can use less space than simple disconnection and can enhance retention. Applicable practices include:

- D-1 Simple disconnection to pervious areas with the compacted cover designation
- D-2 Simple disconnection to conservation areas with the natural cover designation
- D-3 Simple disconnection to a soil compost amended filter path
- D-4 Infiltration by small infiltration practices (dry wells or French drains) (see Section 3.8 Stormwater Infiltration)
- D-5 Filtration by rain gardens or stormwater planters (see Section 3.6 Bioretention)
- D-6 Storage and reuse with a cistern or other vessel (rainwater harvesting) (see Section 3.3 Rainwater Harvesting)

Disconnection practices reduce a portion of the Stormwater Retention Volume (SWRv). In order to meet requirements for larger storm events, disconnection practices must be combined with additional practices.

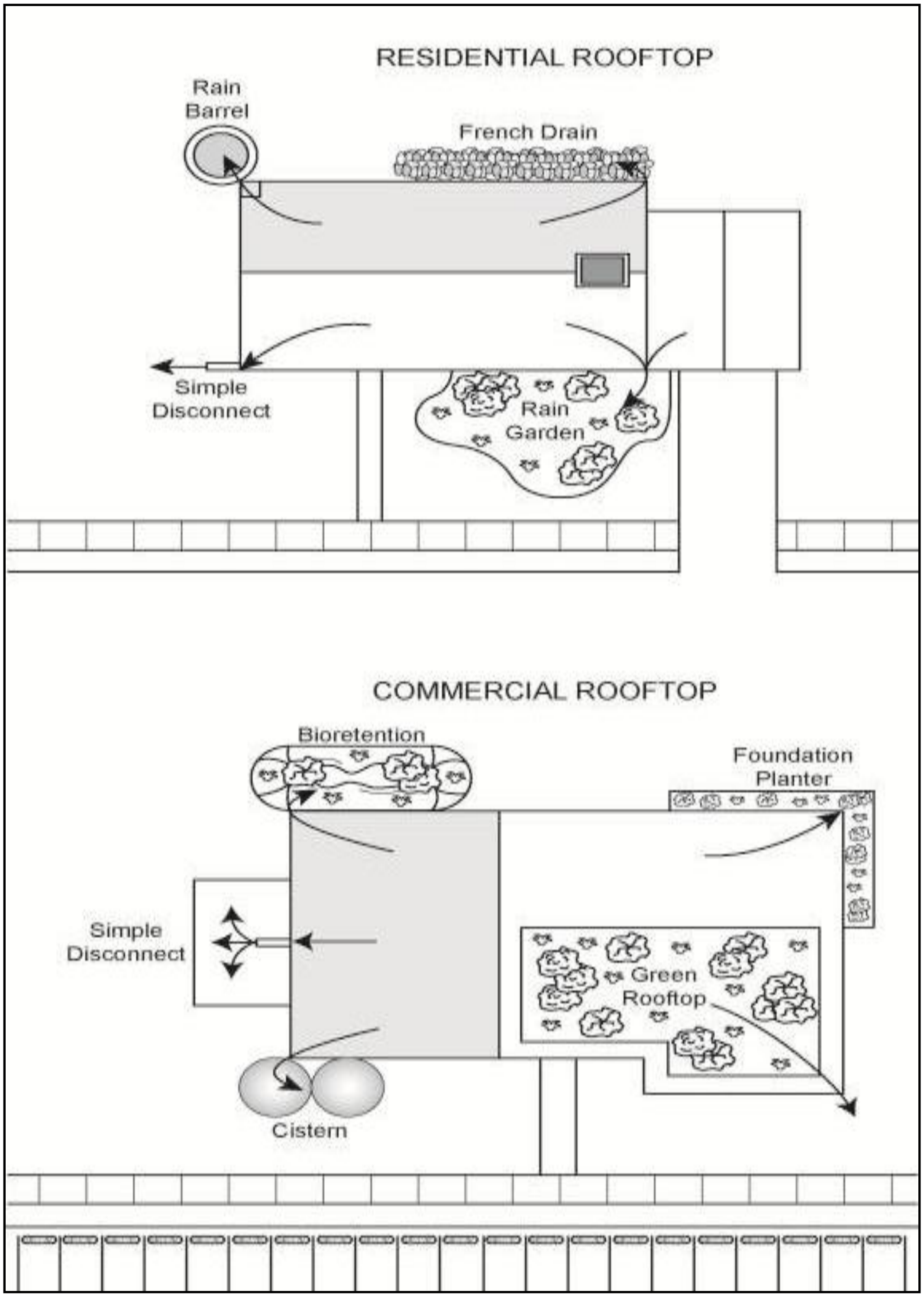

Figure 3.11 Roof disconnection with alternative retention practices

3.4.1 Impervious Surface Disconnection Feasibility Criteria

Impervious surface disconnections are ideal for use on commercial, institutional, municipal, multi-family residential and single-family residential buildings. Key constraints with impervious surface disconnections include available space, soil permeability, and soil compaction.

For disconnection to alternative practices (D-4, D-5, and D-6) consult Sections 3.8, 3.6, and 3.3, respectively. For simple disconnection to compacted cover (D-1) or natural cover (D-2) or soils compost amended filter paths (D-3) the following feasibility criteria exist (also see Table 3.8):

- **Contributing Drainage Area.** For rooftop impervious areas, the maximum impervious area treated cannot exceed 1,000 square feet per disconnection. For impervious areas other than rooftop, the longest contributing impervious area flow path cannot exceed 75 feet.
- **Required Space.** Minimum 150 square feet of disconnection area.
- **Sizing.** The available disconnection area must be at least 10 feet wide and 15 feet long. The disconnection width is limited to 25 feet unless the contributing runoff is conveyed via sheetflow or a level spreader. The disconnection length can be extended up to 100 feet to increase the retention value.
- **Site Topography.** Simple disconnection is best applied when the grade of the receiving pervious area is less than 2 percent, or less than 5 percent with turf reinforcement. The slope of the receiving areas must be graded away from any building foundations. Turf reinforcement may include erosion control matting or other appropriate reinforcing materials that are confirmed by the designer to be erosion resistant for the specific characteristics and flow rates anticipated at each individual application, and acceptable to the plan approving authority.
- **Soils.** Impervious surface disconnection can be used on any post-construction Hydrologic Soil Group. The disconnection area must be kept well-vegetated with minimal bare spots—at least 95 percent soil cover (Section J – Vegetative Stabilization of DDOE's Soil Erosion and Sediment Control Handbook).
- **Building Setbacks.** If the grade of the receiving area is less than 1 percent, downspouts must be extended 5 feet away from building. Note that the downspout extension of 5 feet is intended for simple foundations. The use of a dry well or French drain adjacent to an in-ground basement or finished floor area requires an effective water-proofing system (e.g., foundation drains).

Table 3.8 Feasibility Criteria for Simple Disconnection

Design Factor	Disconnection Design
Contributing Drainage Area	1,000 square feet per rooftop disconnection. For impervious areas other than rooftop, the longest contributing impervious area flow path cannot exceed 75 feet.
Required Space	Minimum 150 square feet of disconnection area.
Sizing	The available disconnection area must be at least 10 feet wide and 15 feet long. Maximum disconnection width is 25 feet unless the contributing runoff is conveyed via sheetflow or a level spreader. Maximum disconnection length is 100 feet.
Site Topography	Grade of the receiving pervious area is less than 2%, or less than 5% with turf reinforcement. The slope of the receiving areas must be graded away from any building foundations.
Soils	Impervious surface disconnection can be used on any post-construction Hydrologic Soil Group. The disconnection area must be kept well-vegetated with minimal bare spots.
Building Setbacks	5 feet away from building if the grade of the receiving area is less than 1%

3.4.2 Impervious Surface Disconnection Conveyance Criteria

Receiving areas in simple disconnection practices (D-1, D-2, and D-3) require a design that safely conveys the 2-year and 15-year storm events over the receiving area without causing erosion. In some applications, erosion control matting or other appropriate reinforcing materials may be needed to control flow rates anticipated for these larger design storms.

For disconnection to alternative practices, consult the appropriate specifications for information on ensuring proper conveyance of the 2-year and 15-year storm events through the practices.

3.4.3 Impervious Surface Disconnection Pretreatment Criteria

Pretreatment is not needed for simple impervious surface disconnection. For disconnection to alternative practices, external downspout pretreatment is recommended (e.g., leaf screens).

3.4.4 Impervious Surface Disconnection Design Criteria

The following design criteria apply to each disconnection practice:

(D-1) Simple Disconnection to a Pervious Area with the Compacted Cover Designation. Disconnection to pervious areas with the compacted cover designation is required to meet the feasibility criteria presented above in Section 3.4.1.

During site construction, care must be taken not to compact the receiving pervious area. To prevent soil compaction, heavy vehicular and foot traffic must be kept out of the receiving pervious area both during and after construction. This can be accomplished by clearly delineating the receiving pervious areas on all development plans and protecting them with temporary fencing prior to the start of land-disturbing activities (see Appendix N for guidance on protecting natural and compacted cover designations during construction). If compaction occurs, soil amendments or post-construction aeration will be required (see Appendix J on soil amendments).

(D-2) Simple Disconnection to a Conservation Area with Natural Cover Designation. Disconnection to conservation areas is required to meet the feasibility criteria presented in Section 3.4.1, with the following additional additions/exceptions:

- Minimum disconnection length is 40 feet.
- Maximum slope of the receiving area is 6 percent. (2 percent for the first 10 feet).
- Inflow must be conveyed via sheet flow or via a level spreader.
- If inflow is conveyed via sheet flow, the maximum flow path is 75 feet when the runoff is conveyed from an impervious area and 150 feet when the runoff is conveyed from a pervious area.
- If inflow is conveyed via a level spreader, the maximum flow path is 150 feet, and the level spreader must be designed with an appropriate width as specified below.
- Retention value applies only to areas directly receiving sheet flow or directly perpendicular to the level spreader.

A level spreader can be used to disperse or “spread” concentrated flow thinly over a vegetated or forested area to promote greater runoff infiltration in the receiving area. A level spreader consists of a permanent linear structure constructed at a 0 percent grade that transects the slope. The influent concentrated runoff must be spread over an area wide enough area so that erosion of the receiving area does not result. Detailed information on the design and function of level spreaders can be found in Hathaway and Hunt, 2006 and NCDWQ, 2010.

The minimum required width of the level spreader is

- 13 linear feet per each 1 cubic foot/second of inflow if the receiving conservation area (natural cover designation) has a minimum 90 percent ground cover
- 40 linear feet per 1 cubic foot/second of inflow if the receiving conservation area (natural cover designation) is forested

(D-3) Simple Disconnection to a Soil Compost-Amended Filter Path. Consult Appendix J for detailed information on the design and function of soil compost amendments. The incorporation of compost amendments must meet the design criteria in the specification and include the following design elements:

- Flow from the downspout must spread over a 10-foot wide strip extending down-gradient along the flow path from the building to the street or conveyance system.
- The filter path must be a minimum 15 feet in length.
- Installation of a pea gravel or river stone diaphragm, or other accepted flow spreading device is required at the downspout outlet to distribute flows evenly across the filter path.

- The strip requires adequate freeboard so that flow remains within the strip and is not diverted away from the strip. In general, this means that the strip should be lower than the surrounding land area in order to keep flow in the filter path. Similarly, the flow area of the filter strip must be level to discourage concentrating the flow down the middle of the filter path.
- Use 2 to 4 inches of compost and till to a depth of 6 to 10 inches within the filter path.

(D-4) Infiltration by Small Infiltration Practices. Depending on soil properties, roof runoff may be infiltrated into a shallow dry well or French drain. The design for this alternative must meet the requirements of infiltration practices, as described in Section 3.8 and summarized in Table 3.9 below. Note that the building setback of 5 feet is intended for simple foundations. The use of a dry well or French drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure’s water-proofing system (e.g., foundation drains), or avoided altogether.

Table 3.9 Design Criteria for Disconnection to Small-Scale Infiltration

Design Factor	Infiltration Design
Roof Area Treated	250 to 2,500 square feet
Typical Practices	Dry well and French drain
Recommended Maximum Depth	3 feet
Sizing	See Section 3.8 Stormwater Infiltration
Observation Well	No
Type of Pretreatment	External (leaf screens, grass strip, etc.)
UIC Permit Needed	Not typically[1]
Head Required	Nominal, 1 to 3 feet
Required Soil Test	One per practice
Building Setbacks	10 feet from structure[2], unless an impermeable liner is used

[1] Infiltration practice must be wider than it is deep. See Section 3.8 Stormwater Infiltration for more information.
[2] Note that the building setback is intended for simple foundations. The use of a dry well or French drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure’s water-proofing system (e.g., foundation drains), or avoided altogether.

In general, micro-infiltration areas will require a surface area up to 3 percent of the contributing roof area. An on-site soil test is needed to determine if soils are suitable for infiltration.

(D-5) Filtration by Rain Gardens or Stormwater Planters. For some residential applications, front, side, and/or rear yard bioretention may be an attractive option used to filter roof runoff (see Figure 3.12). Stormwater planters are also a useful option to disconnect and treat rooftop runoff, particularly in ultra-urban areas. The designs for these options must meet the requirements of stormwater planters (B-4) or rain gardens (B-5), as described in Section 3.6 and summarized in Table 3.10 below.

Figure 3.12 Demonstration sites exist throughout the District to promote downspout disconnection, removing impervious pavement, and promoting native plants.

Table 3.10 Design Criteria for Disconnection to Small-scale Bioretention (D-5)

Design Factor	Bioretention Design
Impervious Area Treated	1,000 square feet (see Section 3.6 Bioretention)
Type of Inflow	Sheetflow or roof leader
Observation Well/ Cleanout Pipes	No
Type of Pretreatment	External (e.g., leaf screens)
Underdrain	Optional per soils (see Section 3.6 Bioretention)
Gravel Layer	12 inches
Minimum Filter Media Depth	18 inches
Media Source	Can be mixed on site
Head Required	Nominal, 1 to 3 feet
Sizing	(See Section 3.6 Bioretention)
Required Soil Test	One per practice
Building Setbacks	10 feet from structure unless an impermeable liner is used

(D-6) Storage and Reuse with a Cistern. This form of disconnection must conform to the design requirements outlined in Section 3.3. Cisterns can be sized for commercial as well as residential purposes. Residential cisterns are commonly called rain barrels.

The retention value for cisterns depends on their storage capacity and ability to draw down water in between storms for reuse as potable water, gray water, or irrigation. The actual retention rate for a particular design can be ascertained using the Rainwater Harvesting Retention Calculator referenced in Section 3.3. All devices must have a suitable overflow area to route extreme flows into the next treatment practice or the stormwater conveyance system.

3.4.5 Impervious Surface Disconnection Landscaping Criteria

All receiving disconnection areas must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. Several appropriate types of grasses for disconnection practices area are listed in Table 3.11. Designers must ensure that the maximum flow velocities do not exceed the values listed in the table for the selected grass species and the specific site slope. If using vegetation outside of this table, the designer must provide documentation to ensure excessive erosion will not occur. Additionally, see the DDOE Soil Erosion and Sediment Control Handbook (Section J – Vegetative Stabilization) for vegetation suggestions.

Table 3.11 Recommended Vegetation for Pervious Disconnection Areas

Vegetation Type	Slope (%)	Maximum Velocity (ft/s)	
		Erosion resistant soil	Easily Eroded Soil
Bermuda Grass	< 5	8	6
	5–10	7	5
	> 10	6	4
Kentucky Bluegrass	< 5	7	5
	5–10	6	4
	> 10	5	3
Tall Fescue Grass Mixture	< 5	6	4
	5–10	4	3
Annual and Perennial Rye	0–5	4	3
Sod	0–5	4	3

Source: USDA, TP-61, 1954; City of Roanoke Virginia Stormwater Design Manual, 2008.

3.4.6 Impervious Surface Disconnection Construction Sequence

Construction Sequence for Disconnection to Pervious Areas. For simple disconnection to a pervious area, the pervious area can be within the limits of disturbance (LOD) during construction. The following procedures should be followed during construction:

- Before site work begins, the receiving pervious disconnection area boundaries should be clearly marked.
- Construction traffic in the disconnection area should be limited to avoid compaction. The material stockpile area shall not be located in the disconnection area.
- Construction runoff should be directed away from the proposed disconnection area, using perimeter silt fence, or, preferably, a diversion dike.
- If existing topsoil is stripped during grading, it shall be stockpiled for later use.

- The disconnection area may require light grading to achieve desired elevations and slopes. This should be done with tracked vehicles to prevent compaction.
- Topsoil and or compost amendments should be incorporated evenly across the disconnection area, stabilized with seed, and protected by biodegradable erosion control matting or blankets.
- Stormwater must not be diverted into any compost amended areas until the area is stabilized, which is defined as having groundcover of 95 percent or greater by the DDOE Soil Erosion and Sediment Control Handbook (Section J – Vegetative Stabilization).

Construction Sequence for Disconnection to Conservation Areas with Natural Cover Designation. For simple disconnection to a conservation area, the conservation area must be fully protected during the construction stage of development and kept outside the LOD on the soil erosion and sediment control plan (SESCP).

- No clearing, grading or heavy equipment access is allowed in the conservation area except temporary disturbances associated with incidental utility construction, restoration operations or management of nuisance vegetation.
- Any conservation areas shall be protected by super silt fence, chain link fence, orange safety fence, or other measures to prevent sediment discharge.
- The LOD must be clearly shown on all construction drawings and identified and protected in the field by acceptable signage, silt fence, snow fence, or other protective barrier.
- If a level spreader is to be used in the design, construction of the level spreader shall not commence until the contributing drainage area has been stabilized and perimeter soil erosion and sediment control measures have been removed and cleaned out. Further, stormwater must not be diverted into the disconnection area until the level spreader is installed and stabilized.

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

DDOE’s construction phase inspection checklist for impervious cover disconnection can be found in Appendix K.

3.4.7 Impervious Surface Disconnection Maintenance Criteria

Maintenance of disconnected downspouts usually involves the regular lawn or landscaping maintenance in the filter path from the roof to the street. In some cases, runoff from a simple disconnection may be directed to a more natural, undisturbed setting (i.e., where lot grading and clearing is “fingerprinted” and the proposed filter path is protected). Typical maintenance activities include erosion control of the receiving area and ensuring the receiving area remains uncompacted and pervious.

DDOE’s maintenance inspection checklists for disconnection can be found in Appendix L.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.4.8 Disconnection Stormwater Compliance Calculations

Disconnection practices receive the following retention values:

D-1 Simple disconnection to a pervious compacted cover area: retention value of 2 cubic feet (15 gallons) per 100 square foot of receiving pervious area (compacted cover).

D-2 Simple disconnection to a conserved natural cover area: retention value of 6 cubic feet (45 gallons) per 100 square foot of receiving pervious conservation area (natural cover).

D-3 Simple disconnection to a soil compost amended filter path: retention value of 4 cubic (30 gallons) feet per 100 square foot of receiving pervious conservation area (soil amended).

D-4 Infiltration by small infiltration practices (dry wells or French drains): see compliance criteria for Section 3.8.

D-5 Filtration by rain gardens or stormwater planters: see compliance criteria for Section 3.6.

D-6 Storage and reuse with a cistern or other vessel (rainwater harvesting): see compliance criteria for Section 3.3.

Note: The surface areas for practices D-1 and D-3 are considered compacted cover for purposes of retention calculations, and the surface area of practice D-2 is considered natural cover.

Simple disconnection practices are not accepted total suspended solids (TSS) treatment practices (see Table 3.12).

Table 3.12 Disconnection Retention Value and Pollutant Removal

Type of Simple Disconnection	Retention Value cubic feet (gallons) per 100 ft^2 of pervious receiving area	Accepted TSS Treatment Practice
To a pervious compacted cover area	2 (15)	No
To a conserved natural cover area	6 (45)	No
To a soil compost amended filter path	4 (30)	No

Impervious surface disconnection also contributes to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the Retention Value from the total runoff volume for the 2-year, 15-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a Reduced Natural Resource Conservation Service Curve Number for the site or drainage area. The Reduced Curve Number can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

3.4.9 References

City of Roanoke Virginia. 2007. Stormwater Design Manual. Department of Planning and Building and Development. Available online at: http://www.roanokeva.gov/85256A8D0062AF37/vwContentByKey/47E4E4ABDDC5DA16852577AD0054958C/$File/Table%20of%20Contents%20%26%20Chapter%201%20Design%20Manual%2008.16.10.pdf

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North Carolina Division of Water Quality (NCDWQ). 2010. Level Spreader-Vegetated Filter Strip System. Stormwater Best Practices Manual. Raleigh, NC. http://portal.ncdenr.org/c/document_library/get_file?uuid=5d698f00-caaa-4f64-ac1f-d1561b4fd53d&groupId=38364

United States Department of Agriculture (USDA). 1954. Handbook of channel design for soil and water conservation. SCS-TP-61. Washington, DC. Available online: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044529.pdf

Virginia DCR Stormwater Design Specification No. 1: Rooftop (Impervious Surface) Disconnection Version 1.8. 2010.

3.5 Permeable Pavement Systems

Definition. This is a paving system that captures and temporarily stores the Stormwater Retention Volume (SWRv) by filtering runoff through voids in an alternative pavement surface into an underlying stone reservoir. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially (or fully) infiltrate into the soil.

Design variants include:

P-1 Porous asphalt (PA)

P-2 Pervious concrete (PC)

P-3 Permeable pavers (PP)

Other variations of permeable pavement that are DDOE-approved permeable pavement surface materials, such as synthetic turf systems with reservoir layer, are also encompassed in this section.

Permeable pavement systems are not typically designed to provide stormwater detention of larger storms (e.g., 2-year, 15-year), but they may be in some circumstances. Permeable pavement practices shall generally be combined with a separate facility to provide those controls.

There are two different types of permeable pavement design configurations:

- **Standard Designs.** Practices with a standard underdrain design and no infiltration sump or water quality filter (see Figure 3.13).
- **Enhanced Designs.** Practices with underdrains that contain a water quality filter layer and an infiltration sump beneath the underdrain sized to drain the design storm in 48 hours (see Figure 3.14) or practices with no underdrains that can infiltrate the design storm volume in 48 hours (see Figure 3.15).

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the underlying soils. These criteria are further discussed below.

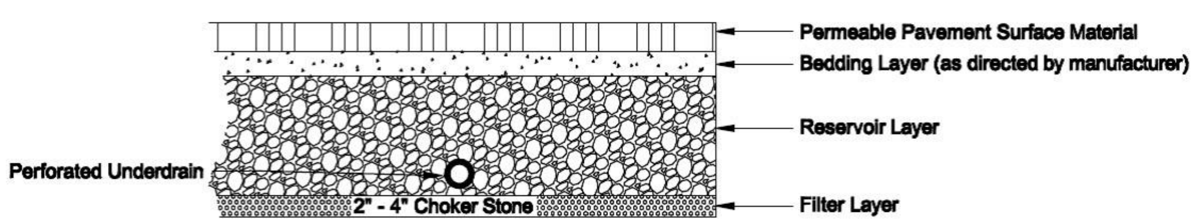

Figure 3.13 Cross section of a standard permeable pavement design.

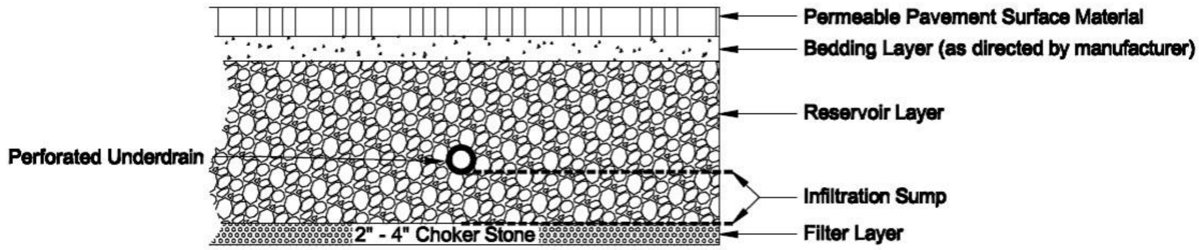

Figure 3.14 Cross section of an enhanced permeable pavement design with an underdrain.

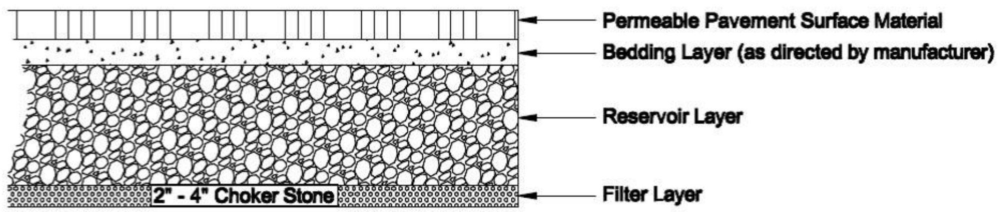

Figure 3.15 Cross section of an enhanced standard permeable pavement design without an underdrain.

3.5.1 Permeable Pavement Feasibility Criteria

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

Required 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.

Soils. Soil conditions do not typically constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Underdrains may be required if the measured permeability of the underlying soils is less than 0.5 inches per hour (although utilization of an infiltration sump may still be feasible). When designing an infiltrating permeable pavement practice, designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix O. Impermeable soils will require an underdrain.

In fill soil locations, geotechnical investigations are required to determine if the use of an impermeable liner and underdrain are necessary or if the use of an infiltration sump is permissible (see Section 3.5.4 Permeable Pavement Design Criteria).

Contributing Drainage Area. The portion of the contributing drainage area that does not include the permeable pavement may not exceed 5 times the surface area of the permeable pavement (2 times is recommended), and it should be as close to 100 percent impervious as possible.

Pavement Surface Slope. Steep pavement surface slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. The permeable pavement slope must be less than 5 percent. Designers may consider using a terraced design for permeable pavement in areas with steeper slopes. In all cases, designs must ensure that the slope of the pavement does not lead to flow occurring out of the stone reservoir layer onto lower portions of the pavement surface.

Minimum Hydraulic Head. The elevation difference needed for permeable pavement to function properly is generally nominal, although 2 to 4 feet of head from the pavement surface to the underdrain outlet is typically necessary. This value may vary based on several design factors, such as required storage depth and underdrain location.

Minimum Depth to Water Table. A high groundwater table may cause runoff to pond at the bottom of the permeable pavement system. Therefore, a minimum vertical distance of 2 feet must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table.

Setbacks. To avoid the risk of seepage, permeable pavement practices must not be hydraulically connected to structure foundations. Setbacks to structures must be at least 10 feet, and adequate water-proofing protection must be provided for foundations and basements. Where the 10-foot setback is not possible, an impermeable liner may be used along the sides of the permeable pavement practice (extending from the surface to the bottom of the practice).

Proximity to Utilities. Interference with underground utilities should be avoided, if possible. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the public right-of-way. Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the permeable paving BMP. For permeable paving BMPs in the public right-of-way, a consolidated presentation of the various utility offset recommendations can be found in Chapter 33.14.5 of the District of Columbia Department of Transportation Design and Engineering Manual, latest edition. Consult the District of Columbia Water and Sewer Authority (DC Water) Green Infrastructure Utility Protection Guidelines, latest edition, for water and sewer line recommendations. Where conflicts cannot be avoided, follow these guidelines:

- Consider altering the location or sizing of the permeable paving BMP to avoid or minimize the utility conflict. Consider an alternate BMP type to avoid conflict.
- Use design features to mitigate the impacts of conflicts that may arise by allowing the permeable paving BMP and the utility to coexist. The permeable paving design may need to incorporate impervious areas, through geotextiles or compaction, to protect utility crossings.
- Work with the utility company to evaluate the relocation of the existing utility and install the optimum placement and sizing of the permeable paving BMP.

- If utility functionality, longevity, and vehicular access to manholes can be assured, accept the permeable paving design and location with the existing utility. Design sufficient soil coverage over the utility or general clearances or other features, such as an impermeable liner, to assure all entities that the conflict is limited to maintenance.

Note: When accepting utility conflict into the permeable paving location and design, it is understood the permeable paving will be temporarily impacted during utility work but the utility will replace the permeable paving or, alternatively, install a functionally comparable permeable paving according to the specifications in the current version of this Stormwater Management Guidebook. Restoration of permeable paving that is located in the public right-of-way will also conform with the District of Columbia Department of Transportation Design and Engineering Manual, with special attention to Chapter 33, Chapter 47, and the Design and Engineering Manual supplements for Low Impact Development and Green Infrastructure Standards and Specifications.

Hotspot Land Uses. Permeable pavements may not be used to treat hotspot runoff. For a list of potential stormwater hotspot operations, consult Appendix P.

On sites with existing contaminated soils, as indicated in Appendix P, infiltration is not allowed. Permeable pavement installations must include an impermeable liner, and the Enhanced Design configuration cannot be used.

High Loading Situations. 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. Sites with a lot of pervious area (e.g., newly established turf and landscaping) can be considered high loading sites and the pervious areas should be diverted if possible from the permeable pavement area. If unavoidable, pretreatment measures, such as a gravel or sod filter strip should be employed (see Section 3.5.3 Permeable Pavement Pretreatment Criteria).

High Speed Roads. Permeable pavement should not be used for high speed roads, although it has been successfully applied for low speed residential streets, parking lanes, and roadway shoulders.

3.5.2 Permeable Pavement Conveyance Criteria

Permeable pavement designs must include methods to convey larger storms (e.g., 2-year, 15-year) to the storm drain system. The following is a list of methods that can be used to accomplish this:

- Place an overdrain—a horizontal perforated pipe near the top of the reservoir layer—to pass excess flows after water has filled the base.
- Increase the thickness of the top of the reservoir layer by as much as 6 inches to increase storage (i.e., create freeboard). The design computations used to size the reservoir layer often assume that no freeboard is present.
- Create underground detention within the reservoir layer of the permeable pavement system. Reservoir storage may be augmented by corrugated metal pipes, plastic or concrete arch structures, etc.

- Route overflows to another detention or conveyance system.
- Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff past the system. The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

3.5.3 Permeable Pavement Pretreatment Criteria

Pretreatment for most permeable pavement applications is not necessary. Additional pretreatment is recommended if the pavement receives run-off from adjacent pervious areas. For example, a gravel or sod filter strip can be placed adjacent to pervious (landscaped) areas to trap coarse sediment particles before they reach the pavement surface in order to prevent premature clogging.

3.5.4 Permeable Pavement Design Criteria

Type of Surface Pavement. The type of pavement should be selected based on a review of the pavement specifications and properties and designed according to the product manufacturer's recommendations.

Pavement Bottom Slope. For unlined designs, the bottom slope of a permeable pavement installation should be as flat as possible (i.e., 0 percent longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater. On sloped sites, internal check dams or berms, as shown in the diagram Figure 3.16 below, can be incorporated into the subsurface to encourage infiltration. In this type of design, the depth of the infiltration sump would be the depth behind the check dams. The depth and spacing of the barriers is dependent upon the underlying slope and the infiltration rate, as any water retained by the flow barriers must infiltrate within 48 hours. If an underdrain will be used in conjunction with the flow barriers, it can be installed over the top of the barriers, or parallel to the barriers with an underdrain in each cell.

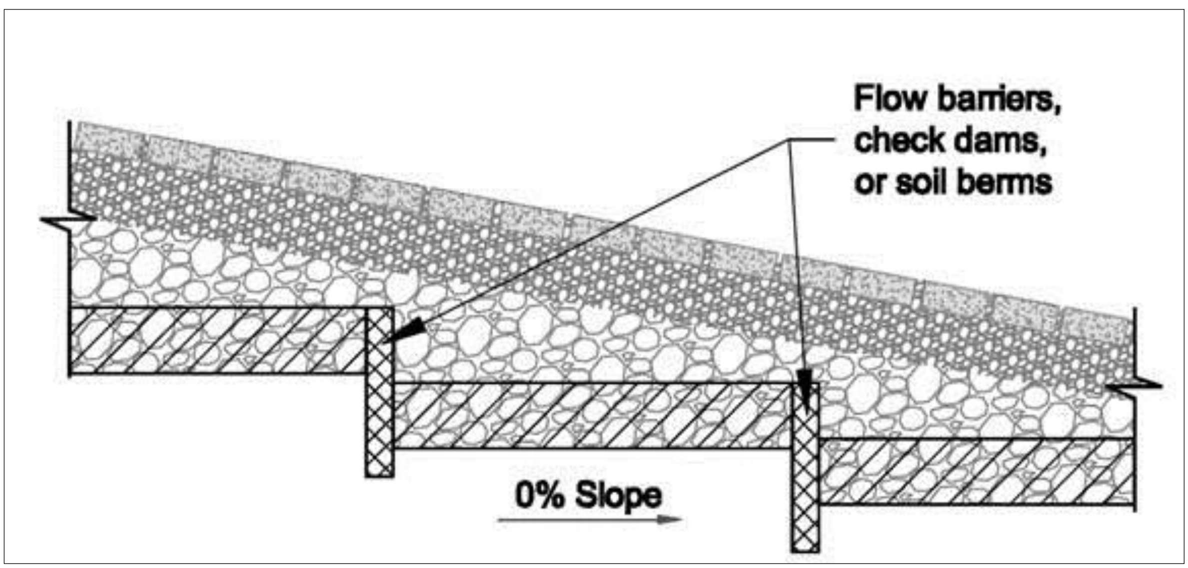

Figure 3.16 Use of flow barriers to encourage infiltration on sloped sites.

Internal Geometry and Drawdowns.

- **Rapid Drawdown.** Permeable pavement must be designed so that the target storage volume is detained in the reservoir for as long as possible—36 to 48 hours—before completely discharging through an underdrain. A minimum orifice size of 1 inch is recommended regardless of the calculated drawdown time.

  Note: A 48-hour maximum drawdown time is utilized for permeable pavement rather than the 72-hour value used for other BMPs. This shorter drawdown time, in accordance with industry standards, is intended to ensure that the subgrade does not stay saturated for too long and cause problems with the pavement.
- **Infiltration Sump.** To promote greater retention for permeable pavement located on marginal soils, an infiltration sump can be installed to create a storage layer below the underdrain invert. This design configuration is discussed further below.
- **Conservative Infiltration Rates.** Designers must use 1/2 of the measured infiltration rate during design to approximate long-term infiltration rates (for example, if the measured infiltration rate is 0.7 inches per hour, the design infiltration rate will be 0.35 inches per hour). This requirement is included in Equation 3.2 through Equation 3.4.

Reservoir Layer. The reservoir layer consists of the stone underneath the pavement section and above the bottom filter layer or underlying soils, including the optional infiltration sump. The total thickness of the reservoir layer is determined by runoff storage needs, the infiltration rate of in situ soils, structural requirements of the pavement sub-base, depth to water table and bedrock, and frost depth conditions (see Section 3.5.1 Permeable Pavement Feasibility Criteria). A geotechnical engineer should be consulted regarding the suitability of the soil subgrade.

- The reservoir below the permeable pavement surface should be composed of clean, double-washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading (additional chamber structures may also be used to create larger storage volumes).
- The storage layer may consist of clean, double-washed No. 57 stone, although No. 2 stone is preferred because it provides additional structural stability. Other appropriate materials may be used if accepted by DDOE.
- The bottom of the reservoir layer should be completely flat so that runoff will be able to infiltrate evenly through the entire surface. The use of terracing and check dams is permissible.

Underdrains. Most permeable pavement designs will require an underdrain (see Section 3.5.1 Permeable Pavement Feasibility Criteria). Underdrains can also be used to keep detained stormwater from flooding permeable pavement during extreme events. Multiple underdrains are necessary for permeable pavement wider than 40 feet, and each underdrain must be located 20 feet or less from the next pipe or the edge of the permeable pavement. (For long and narrow applications, a single underdrain running the length of the permeable pavement is sufficient.) The underdrain should be perforated schedule 40 PVC pipe (corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center. The underdrain must be encased in a layer of clean, double washed No. 57 stone, with a minimum 2-

inch cover over the top of the underdrain. The underdrain system must include a flow control to ensure that the reservoir layer drains slowly (within 36 to 48 hours).

- The underdrain outlet can be fitted with a flow-reduction orifice within a weir or other easily inspected and maintained configuration in the downstream manhole as a means of regulating the stormwater detention time. The minimum diameter of any orifice is 1 inch. The designer should verify that the volume will draw down completely within 36 to 48 hours.
- On infiltration designs, an underdrain(s) can be installed and capped at the downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.

All permeable pavement practices must include observation wells. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event and to facilitate periodic inspection and maintenance. The observation well should consist of a well-anchored, perforated 4- to 6-inch diameter PVC pipe that is tied into any Ts or Ys in the underdrain system. The well should extend vertically to the bottom of the reservoir layer and extend upwards to be flush with the surface (or just under pavers) with a lockable cap.

Infiltration Sump (optional, required for underdrained Enhanced Designs). For unlined permeable pavement systems, an optional upturned elbow or elevated underdrain configuration can be used to promote greater retention for permeable pavement located on marginal soils (see Figure 3.14). The infiltration sump must be installed to create a storage layer below the underdrain or upturned elbow invert. The depth of this layer must be sized so that the design storm can infiltrate into the subsoils in a 48-hour period. The bottom of the infiltration sump must be at least 2 feet above the seasonally high water table. The inclusion of an infiltration sump is not permitted for designs with an impermeable liner. In fill soil locations, geotechnical investigations are required to determine if the use of an infiltration sump is permissible.

In order to improve the infiltration rate of the sump, it may be designed as a series of 1-foot wide trenches spread 5 feet apart, which are excavated after compaction of the existing soils is performed. Excavation of these trenches may allow access to less compacted, higher permeability soils and improve the effectiveness of the infiltration sump (Brown and Hunt, 2009). Regardless of the infiltration sump design, the infiltration rate must be field verified.

Filter Layer (optional). To protect the bottom of the reservoir layer from intrusion by underlying soils, a filter layer can be used. The underlying native soils should be separated from the stone reservoir by a 2 to 4 inch layer of choker stone (e.g., No. 8).

Geotextile (optional). Geotextile fabric is another option to protect the bottom of the reservoir layer from intrusion by underlying soils, although some practitioners recommend avoiding the use of fabric beneath permeable pavements since it may become a future plane of clogging within the system. Geotextile fabric is still recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used.

Impermeable Liner. An impermeable liner is not typically required, although it may be utilized in fill applications where deemed necessary by a geotechnical investigation, on sites with contaminated soils, or on the sides of the practice to protect adjacent structures from seepage. Use a 30-mil (minimum) PVC geomembrane liner. (Follow manufacturer's instructions for installation.) Field seams must be sealed according to the liner manufacturer's specifications. A minimum 6-inch overlap of material is required at all seams.

Material Specifications. Permeable pavement material specifications vary according to the specific pavement product selected. A general comparison of different permeable pavements is provided in Table 3.13 below, but designers should consult manufacturer's technical specifications for specific criteria and guidance. Table 3.14 describes general material specifications for the component structures installed beneath the permeable pavement. Note that the size of stone materials used in the reservoir and filter layers may differ depending on the type of surface material.

Table 3.13 Permeable Pavement Specifications for a Variety of Typical Surface Materials

Material	Specification	Notes
Permeable Pavers (PP)	Void content, thickness, and compressive strength vary based on type and manufacturer Open void fill media: aggregate, topsoil and grass, coarse sand, etc.	Reservoir layer required to support the structural load.
Pervious Concrete (PC)	Void content: 15% to 25%. Thickness: typically 4 to 8 inches. Compressive strength: 2.8 to 28 MPa. Open void fill media: None	May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or infiltration.
Porous Asphalt (PA)	Void content: 15% to 20%. Thickness: typically 3 to 7 in. (depending on traffic load). Open void fill media: None.	Reservoir layer required to support the structural load.

Table 3.14 Material Specifications for Typical Layers Beneath the Pavement Surface

Material	Specification	Notes
Bedding Layer	PC: 3 to 4 inches of No. 57 stone if No. 2 stone is used for Reservoir Layer PA: 3 to 4 inches of No. 57 stone PP: Follow manufacturer specifications	ASTM D448 size No. 8 stone (e.g., 3/8 to 3/16 inch in size). Must be double-washed and clean and free of all fines.
Reservoir Layer	PC: No. 57 stone or No. 2 stone PA: No. 2 stone PP: Follow manufacturer specifications	ASTM D448 size No. 57 stone (e.g., 1 1/2 to 1/2-inch in size); No. 2 Stone (e.g., 3 inches to 3/4 inches in size). Depth is based on the pavement structural and hydraulic requirements. Must be double-washed and clean and free of all fines. Other appropriate materials may be used if accepted by DDOE.

Material	Specification	Notes
Underdrain	Use 4- to 6-inch diameter perforated PVC pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center. Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. T's and Y's should be installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface.	
Infiltration Sump (optional)	An aggregate storage layer below the underdrain invert. The material specifications are the same as Reservoir Layer.	
Filter Layer (optional)	The underlying native soils should be separated from the stone reservoir by a 2 to 4 inch layer of choker stone (e.g., No. 8).	
Geotextile (optional)	Use an appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability.	
Impermeable Liner (optional)	Where appropriate use a thirty mil (minimum) PVC Geomembrane liner (follow manufacturer's instructions for installation)	
Observation Well	Use a perforated 4- to 6-inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface.	

Permeable Pavement Sizing. The thickness of the reservoir layer is determined by both a structural and hydraulic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. Permeable pavement structural and hydraulic sizing criteria are discussed below.

Structural Design. If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations should be consulted. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (e.g., the water quality, channel protection, and/or flood control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavements involves consideration of four main site elements:

- Total traffic
- In-situ soil strength
- Environmental elements
- Bedding and reservoir layer design

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 percent), they may need to be compacted to at least 95 percent of the Standard Proctor Density, which may limit their use for infiltration.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- AASHTO Guide for Design of Pavement Structures (1993)
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998)

Hydraulic Design. Permeable pavement is typically sized to store the SWRv or larger design storm volumes in the reservoir layer. The storage volume in the pavements must account for the underlying infiltration rate and outflow through any underdrains. The design storm should be routed through the pavement to accurately determine the required reservoir depth. The depth of the reservoir layer or infiltration sump needed to store the design storm can be determined by using Equation 3.2.

Equation 3.2 Reservoir Layer or Infiltration Sump Depth

$$d_p = \frac{\left(\dfrac{P \times Rv_I \times DA}{A_p}\right) - \left(\dfrac{i}{2} \times t_f\right)}{\eta_r}$$

where:

d_p	=	depth of the reservoir layer (or depth of the infiltration sump for enhanced designs with underdrains) (ft)
P	=	rainfall depth for the SWRv or other design storm (ft)
Rv_I	=	runoff coefficient for impervious cover (0.95)
DA	=	total drainage area, including contributing drainage area and permeable pavement surface area (ft^2)
A_p	=	permeable pavement surface area (ft^2)
i	=	field-verified infiltration rate for the subgrade soils (ft/day). If an impermeable liner is used in the design then i = 0.
t_f	=	time to fill the reservoir layer (day) (assume 2 hours or 0.083 day)
η_r	=	effective porosity for the reservoir layer (0.35)

This equation makes the following design assumptions:

- The contributing drainage area (DA) does not contain pervious areas.
- For design purposes, the field-tested subgrade soil infiltration rate (i) is divided by 2 as a factor of safety to account for potential compaction during construction. If the subgrade will be compacted to meet structural design requirements of the pavement section, the design infiltration rate of the subgrade soil shall be based on measurement of the infiltration rate of the subgrade soil subjected to the compaction requirements.
- The porosity (η_r) for No. 57 stone is 0.35.

The depth of the reservoir layer cannot be less than the depth required to meet the pavement structural requirement. The depth of the reservoir layer may need to be increased to meet structural or larger storage requirements.

Designers must ensure that the captured volume will drain from the pavement in 36 to 48 hours. For infiltration designs without underdrains or designs with infiltration sumps, Equation 3.3 can be used to determine the drawdown time in the reservoir layer or infiltration sump.

Equation 3.3 Drawdown Time

$$t_d = \frac{d_p \times \eta_r}{\left(\frac{i}{2}\right)} = \frac{d_p \times \eta_r \times 2}{i}$$

where:

t_d	=	drawdown time (specify unit of measure)
d_p	=	depth of the reservoir layer (or the depth of the infiltration sump, for enhanced designs with underdrains) (ft)
η_r	=	effective porosity for the reservoir layer (0.35)

For designs with underdrains, the drawdown time should be determined using the hydrological routing or modeling procedures used for detention systems with the depth and head adjusted for the porosity of the aggregate.

The total storage volume provided by the practice, Sv, should be determined using Equation 3.4.

Equation 3.4 Permeable Pavement Storage Volume

$$Sv = \left(d_p \times \eta_r \times A_p\right) + \left(\frac{i \times t_f}{2}\right)$$

where:

Sv	=	storage volume (ft^3)
d_p	=	depth of the reservoir layer (or depth of the infiltration sump for enhanced designs with underdrains) (ft)
η_r	=	effective porosity for the reservoir layer (0.35)
A_p	=	permeable pavement surface area (ft^2)
i	=	field-verified infiltration rate for the subgrade soils (ft/day). If an impermeable liner is used in the design then i = 0.
t_f	=	time to fill the reservoir layer (day) (assume 2 hours or 0.083 day)

Detention Storage Design. Permeable pavement can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer (including chamber structures that increase the available storage volume), expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

Once runoff passes through the surface of the permeable pavement system, designers should calculate outflow pathways to handle subsurface flows. Subsurface flows can be regulated using underdrains, the volume of storage in the reservoir layer, the bed slope of the reservoir layer, and/or a control structure at the outlet (see Section 3.5.2 Permeable Pavement Conveyance Criteria).

3.5.5 Permeable Pavement Landscaping Criteria

Permeable pavement does not have any landscaping needs associated with it. However, large-scale permeable pavement applications should be carefully planned to integrate the typical landscaping features of a parking lot, such as trees and islands, in a manner that maximizes runoff treatment and minimizes the risk that sediment, mulch, grass clippings, leaves, nuts, and fruits will inadvertently clog the paving surface. Bioretention areas (see Section 3.6 Bioretention) may be a good design option to meet these needs.

3.5.6 Permeable Pavement Construction Sequence

Experience has shown that proper installation is absolutely critical to the effective operation of a permeable pavement system.

Soil Erosion and Sediment Controls. The following soil erosion and sediment control guidelines must be followed during construction:

- All permeable pavement areas must be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.
- Permeable pavement areas intended to infiltrate runoff must remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment and loss of design infiltration rate (unless the area has been determined to have a low CBR and will require compaction during the permeable pavement construction phase). Where it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, there are several possible outcomes for the impacted area.
    - If excavation in the proposed permeable pavement areas can be restricted then remediation can be achieved with deep tilling practices. This is only possible if in-situ soils are not disturbed any deeper than 2 feet above the final design elevation of the bottom of the aggregate reservoir course. In this case, when heavy equipment activity has ceased, the area is excavated to grade, and the impacted area must be tilled to a depth of 12 inches below the bottom of the reservoir layer.
    - Alternatively, if it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, and excavation of the area cannot be restricted cannot be met, then infiltration tests will be required prior to installation of the permeable pavement to ensure that the design infiltration rate is still present. If tests reveal the loss of design

infiltration rates then deep tilling practices may be used in an effort to restore those rates. In this case further testing must be done to establish design rates exist before the permeable pavement can be installed.

- ♦ Finally, if it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, and excavation of the area cannot be restricted, and infiltration tests reveal design rates cannot be restored, then a resubmission of the SWMP will be required.

- Permeable pavement areas must be clearly marked on all construction documents and grading plans.
- During construction, care should be taken to avoid tracking sediments onto any permeable pavement surface to avoid post construction clogging and long term maintenance issues.
- Any area of the site intended ultimately to be a permeable pavement area with an infiltration component must not be used as the site of a temporary sediment trap or basin. If locating a temporary sediment trap or basin on an area intended for permeable pavement is unavoidable, the outcomes are parallel to those discussed for heavy equipment compaction.
    - ♦ If it is possible restrict the invert of the sediment trap or basin at least 1 foot above the final design elevation of the bottom of the aggregate reservoir course of the proposed permeable pavement then remediation can be achieved with proper removal of trapped sediments and deep tilling practices.
    - ♦ An alternate approach to deep tilling is to use an impermeable linear to protect the in-situ soils from sedimentation while the sediment trap or basin is in use.
    - ♦ In each case, all sediment deposits in the excavated area must be carefully removed prior to installing the sub-base, base, and surface materials. The plan must also show the proper procedures for converting the temporary sediment control practice to a permeable pavement BMP, including dewatering, cleanout, and stabilization.

Permeable Pavement Installation. The following is a typical construction sequence to properly install permeable pavement, which may need to be modified depending on the particular type of permeable pavement that is being installed.

Step 1: **Stabilize Drainage Area.** Construction of the permeable pavement should only begin after the entire contributing drainage area has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow and do not install frozen bedding materials.

Step 2: **Install Soil Erosion and Sediment Control Measures for the Bioretention.** As noted above, temporary soil erosion and sediment controls are needed during installation to divert stormwater away from the permeable pavement area until it is completed. Special protection measures, such as erosion control fabrics, may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed permeable pavement area must be kept free from sediment during the entire construction process. Construction materials contaminated by sediment must be removed and replaced with clean material.

Step 3: **Minimize Impact of Heavy Installation Equipment.** Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions. For small pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the permeable pavement area (to avoid compaction). Contractors can utilize a cell construction approach, whereby the proposed permeable pavement area is split into 500- to 1,000-square foot temporary cells with a 10- to 15-foot wide earth bridge in between, so cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

Step 4: **Promote Infiltration Rate.** The native soils along the bottom of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the filter layer or geotextile fabric. In large-scale paving applications with weak soils, the soil subgrade may need to be compacted to 95 percent of the Standard Proctor Density to achieve the desired load-bearing capacity.

Note: This may reduce or eliminate the infiltration function of the installation, and it must be addressed during hydrologic design.

Step 5: **Order of Materials.** Geotextile fabric should be installed on the sides of the reservoir layer (and the bottom if the design calls for it). Geotextile fabric strips should overlap down-slope by a minimum of 2 feet and be secured a minimum of 4 feet beyond the edge of the excavation. Where the filter layer extends beyond the edge of the pavement (to convey runoff to the reservoir layer), install an additional layer of geotextile fabric 1 foot below the surface to prevent sediment from entering into the reservoir layer. Excess geotextile fabric should not be trimmed until the site is fully stabilized.

Step 6: **Install Base Material Components.** Provide a minimum of 2 inches of aggregate above and below the underdrains. The up-gradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there shall be no perforations within 1 foot of the structure. Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.

Step 7: **Stone Media**. Spread 6-inch lifts of the appropriate clean, double washed stone aggregate (usually No. 2 or No. 57 stone). Place at least 4 inches of additional aggregate above the underdrain, and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate. Do not crush the aggregate with the roller.

Step 8: **Reservoir Media**. Install the desired depth of the bedding layer, depending on the type of pavement, as indicated in Table 3.14.

Step 9: **Paving Media**. Paving materials shall be installed in accordance with manufacturer or industry specifications for the particular type of pavement.

Installation of Porous Asphalt. The following has been excerpted from various documents, most notably Jackson (2007):

- Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course. The laying temperature should be between 230oF and 260oF, with a minimum air temperature of 50°F, to ensure the surface does not stiffen before compaction.

- Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.
- The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM 1664. If the estimated coating area is not above 95 percent, additional anti-stripping agents must be added to the mix.
- Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.
- Test the full permeability of the pavement surface by application of clean water at a rate of at least five gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.
- Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding to determine if the facility is draining properly.

Installation of Pervious Concrete. The basic installation sequence for pervious concrete is outlined by the National Ready Mixed Concrete Association (NRMCA) (NRMCA 2004). It is strongly recommended that concrete installers successfully complete a recognized pervious concrete installers training program, such as the Pervious Concrete Contractor Certification Program offered by the NRMCA. The basic installation procedure is as follows:

- Drive the concrete truck as close to the project site as possible.
- Water the underlying aggregate (reservoir layer) before the concrete is placed, so the aggregate does not draw moisture from the freshly laid pervious concrete.
- After the concrete is placed, approximately 3/8 to 1/2 inches is struck off, using a vibratory screed. This is to allow for compaction of the concrete pavement.
- Compact the pavement with a steel pipe roller. Care should be taken to ensure over-compaction does not occur.
- Cut joints for the concrete to a depth of 1/4 inch.
- The curing process is very important for pervious concrete. Concrete installers should follow manufacturer specifications to the extent allowed by on-site conditions when curing pervious concrete. This typically requires covering the pavement with plastic sheeting within 20 minutes of the strike-off, and may require keeping it covered for at least seven (7) days. Do not allow traffic on the pavement during the curing period.
- Remove the plastic sheeting only after the proper curing time. Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding, to determine if the facility is draining properly.

Installation of Permeable Interlocking Concrete Pavers. The basic installation process is described in greater detail by Smith (2006):

- Place edge restraints for open-jointed pavement blocks before the bedding layer and pavement blocks are installed. Permeable interlocking concrete pavement (IP) systems require edge restraints to prevent vehicle loads from moving the paver blocks. Edge restraints may be standard curbs or gutter pans, or precast or cast-in-place reinforced concrete borders a minimum of 6 inches wide and 18 inches deep, constructed with Class A3 concrete. Edge restraints along the traffic side of a permeable pavement block system are recommended.

- Place the double washed No. 57 stone in a single lift. Level the filter course and compact it into the reservoir course beneath with at least four passes of a 10-ton steel drum static roller until there is no visible movement. The first 2 passes are in vibratory mode, with the final 2 passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
- Place and screed the bedding course material (typically No. 8 stone).
- Fill gaps at the edge of the paved areas with cut pavers or edge units. When cut pavers are needed, cut the pavers with a paver splitter or masonry saw. Cut pavers no smaller than 1/3 of the full unit size.
- Pavers may be placed by hand or with mechanical installers. Fill the joints and openings with stone. Joint openings must be filled with ASTM D 448 No. 8 stone; although, No. 8P or No. 9 stone may be used where needed to fill narrower joints. Remove excess stones from the paver surface.
- Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000-lbf, 75- to 95-Hz plate compactor.
- Do not compact within 6 feet of the unrestrained edges of the pavers.
- The system must be thoroughly swept by a mechanical sweeper or vacuumed immediately after construction to remove any sediment or excess aggregate.
- Inspect the area for settlement. Any blocks that settle must be reset and re-inspected.
- Inspect the facility 18 to 30 hours after a significant rainfall (1/2 inch or greater) or artificial flooding to determine whether the facility is draining properly.

Construction Supervision. Supervision before, during, and after construction by a qualified professional is recommended to ensure permeable pavement is built in accordance with these specifications. Inspection checklists that require sign-offs by qualified individuals should be used at critical stages of construction to ensure the contractor’s interpretation of the plan is consistent with the designer’s intent.

DDOE’s construction phase inspection checklist for permeable pavement practices can be found in Appendix K.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of permeable pavement installation:

- Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
- The contributing drainage area should be stabilized prior to directing water to the permeable pavement area.

- Check the aggregate material to confirm it is clean and washed, meets specifications and is installed to the correct depth. Aggregate loads that do not meet the specifications or do not appear to be sufficiently washed may be rejected.
- Check elevations (e.g., the invert of the underdrain, inverts for the inflow, and outflow points.) and the surface slope.
- Make sure the permeable pavement surface is even, runoff spreads evenly across it, and the storage bed drains within 48 hours.
- Ensure caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Inspect the pretreatment structures (if applicable) to make sure they are properly installed and working effectively.
- Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the BMP maintenance tracking database.

Runoff diversion structures are recommended to protect larger permeable pavement applications from early runoff-producing storms away from, particularly when up-gradient conventional asphalt areas drain to the permeable pavement. This can help reduce the input of fine particles often produced shortly after conventional asphalt is laid.

3.5.7 Permeable Pavement Maintenance Criteria

Maintenance is a required and crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment. Periodic street sweeping will remove accumulated sediment and help prevent clogging; however, it is also critical to ensure that surrounding land areas remain stabilized.

The following tasks must be avoided on ALL permeable pavements:

- Sanding
- Re-sealing
- Re-surfacing
- Power washing
- Storage of snow piles containing sand
- Storage of mulch or soil materials
- Construction staging on unprotected pavement

It is difficult to prescribe the specific types or frequency of maintenance tasks that are needed to maintain the hydrologic function of permeable pavement systems over time. The frequency of maintenance will depend largely on the pavement use, traffic loads, and the surrounding land use.

One preventative maintenance task for large-scale applications (e.g., parking lots) involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the site.

Many experts 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. Typical maintenance tasks are outlined in Table 3.15.

Table 3.15 Typical Maintenance Tasks for Permeable Pavement Practices

Frequency	Maintenance Tasks
After installation	▪ For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization.
Once every 1–2 months during the growing season	▪ Mow grass in grid paver applications
As needed	▪ Stabilize the CDA to prevent erosion ▪ Remove any soil or sediment deposited on pavement. ▪ Replace or repair any pavement surfaces that are degenerating or spalling
2–4 times per year (depending on use)	▪ Mechanically sweep pavement with a standard street sweeper to prevent clogging
Annually	▪ Conduct a maintenance inspection ▪ Spot weed for grass applications
Once every 2–3 years	▪ Remove any accumulated sediment in pretreatment cells and inflow points
If clogged	▪ Conduct maintenance using a regenerative street sweeper or a vacuum sweeper ▪ Replace any necessary joint material

Seasonal Maintenance Considerations: Winter maintenance for permeable pavements is similar to standard pavements, with a few additional considerations:

- Large snow storage piles should be located in adjacent grassy areas so that sediment and pollutants in snowmelt are partially treated before they reach the permeable pavement.
- Sand or cinders should never be applied for winter traction over permeable pavement or areas of standard (impervious) pavement that drain toward permeable pavement, since it will quickly clog the system.
- When plowing plastic reinforced grid pavements, snow plow blades should be lifted 1/2 inch to 1 inch above the pavement surface to prevent damage to the paving blocks or turf. Porous asphalt (PA), pervious concrete (PC), and some permeable pavers (PP) can be plowed similar to traditional pavements, using similar equipment and settings.
- Chloride products should be used judiciously to deice above permeable pavement designed for infiltration, since the salt will be transmitted through the pavement. Salt can be applied but environmentally sensitive deicers are recommended. Permeable pavement applications will generally require less salt application than traditional pavements.

When permeable pavements are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs and (2) understand the long-term maintenance plan.

It is recommended that a qualified professional conduct a spring maintenance inspection and cleanup at each permeable pavement site, particularly at large-scale applications. DDOE's maintenance inspection checklists for permeable pavements and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.5.8 Permeable Pavement Stormwater Compliance Calculations

Permeable pavement retention value varies depending on the design configuration of the system.

Enhanced Designs. These permeable pavement applications have an infiltration sump and water-quality filter, but no underdrain. Enhanced designs receive 100 percent retention value for the amount of storage volume (Sv) provided by the practice (Table 3.16). Since the practice gets 100 percent retention value, it is not considered an accepted total suspended solids (TSS) treatment practice.

Table 3.16 Enhanced Permeable Pavement Retention Value and Pollutant Removal

Retention Value	= *Sv*
Accepted TSS Treatment Practice	N/A

Note: If using an infiltration sump design, only the volume stored in the sump can be counted as the Enhanced Design Storage Volume (Sv). Any volume stored in the practice above the sump is counted as a standard design. When using the Site Design Spreadsheet, the Sv of the infiltration sump should be entered into the cell "Storage Volume Provided by the Practice" in the Permeable Pavement – Enhanced row. Permeable Pavement – Standard should then be selected as the downstream practice. Next, in the Permeable Pavement - Standard row, the Sv provided above the infiltration sump should be entered into the cell "Storage Volume Provided by the Practice," and the surface area of the pavement should be entered in the "Area of Practice" cell.

Standard Designs. These permeable pavement applications have an underdrain, but no infiltration sump or water quality filter. Standard designs receive a retention value of 4.5 cubic feet per 100 square feet of practice area and are an accepted TSS removal practice for the amount of storage volume (Sv) provided by the practice (Table 3.17).

Table 3.17 Standard Permeable Pavement Retention Value and Pollutant Removal

Retention Value	= *Sv*
Accepted TSS Treatment Practice	N/A

The practice must be sized using the guidance detailed in Section 3.5.4.

Permeable pavement also contributes to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the retention value achieved by the practice from the total runoff volume for the 2-year, 15-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a Reduced Natural Resource Conservation Service Curve Number for the site or drainage area. The Reduced Curve Number can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

3.5.9 References

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3.6 Bioretention

Definition. Practices that capture and store stormwater runoff and pass it through a filter bed of engineered soil media composed of sand, soil, and organic matter. Filtered runoff may be collected and returned to the conveyance system, or allowed to infiltrate into the soil. Design variants include:

B-1 Traditional bioretention

B-2 Streetscape bioretention

B-3 Engineered tree pits

B-4 Stormwater planters

B-5 Residential rain gardens

Bioretention systems are typically not designed to provide stormwater detention of larger storms (e.g., 2-year, 15-year), but they may be in some circumstances. Bioretention practices shall generally be combined with a separate facility to provide those controls.

There are two different types of bioretention design configurations:

- **Standard Designs**. Practices with a standard underdrain design and less than 24 inches of filter media depth (see Figure 3.17). If trees are planted using this design, the filter media depth must be at least 24 inches to support the trees.
- **Enhanced Designs**. Practices with underdrains that contain at least 24 inches of filter media depth and an infiltration sump/storage layer (see Figure 3.18) or practices that can infiltrate the design storm volume in 72 hours (see Figure 3.19).

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the underlying soils. These criteria are further discussed in this chapter.

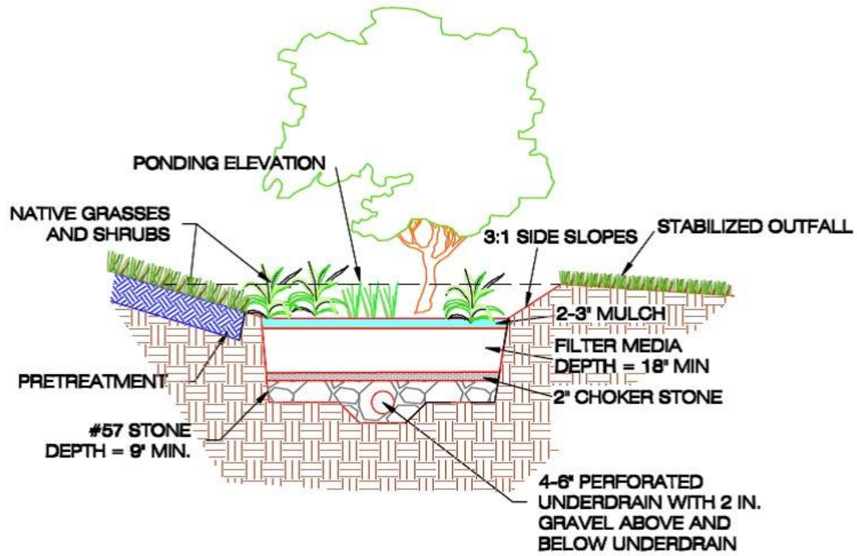

Figure 3.17 Example of standard bioretention design.

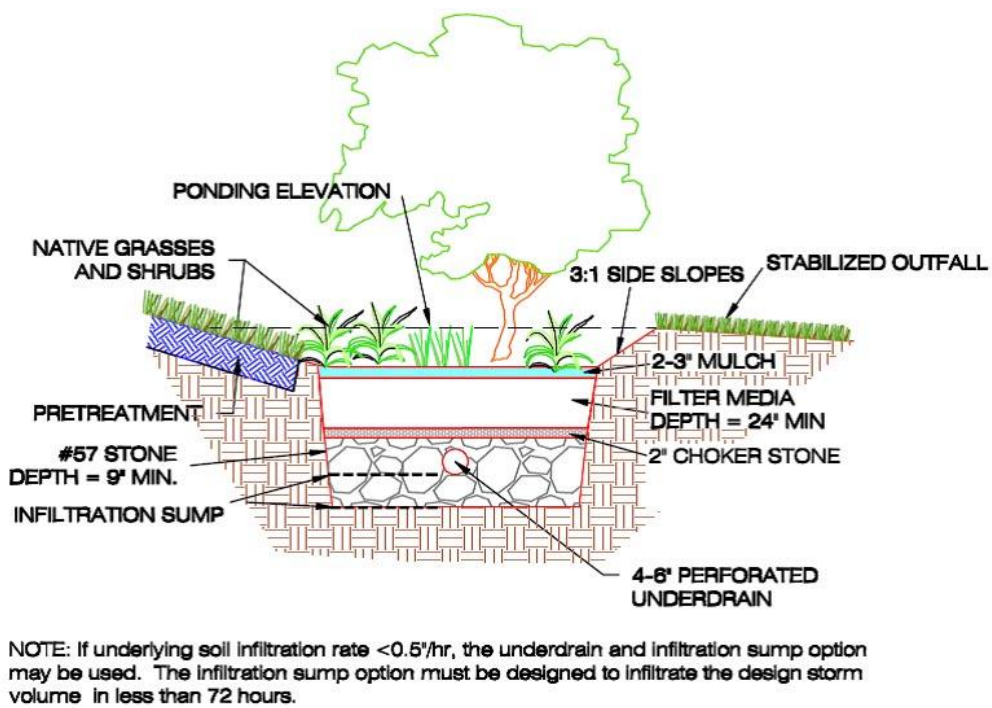

Figure 3.18 Example of an enhanced bioretention design with an underdrain and infiltration sump/storage layer.

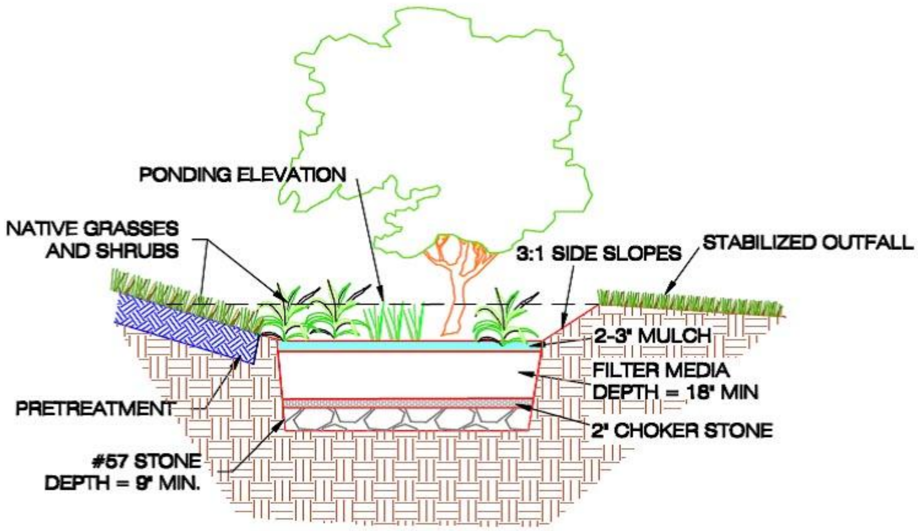

Figure 3.19 Example of enhanced bioretention design without an underdrain.

3.6.1 Bioretention Feasibility Criteria

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

Required Space. Planners and designers can assess the feasibility of using bioretention facilities based on a simple relationship between the contributing drainage area (CDA), and the corresponding bioretention surface area. The surface area is recommended to be approximately 3 to 6 percent of CDA, depending on the imperviousness of the CDA and the desired bioretention ponding depth.

Available Hydraulic Head. Bioretention is fundamentally constrained by the invert elevation of the existing conveyance system to which the practice discharges (i.e., the bottom elevation needed to tie the underdrain from the bioretention area into the storm drain system). In general, 4 to 5 feet of elevation above this invert is needed to accommodate the required ponding and filter media depths. If the practice does not include an underdrain or if an inverted or elevated underdrain design is used, less hydraulic head may be adequate.

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

Soils and Underdrains. Soil conditions do not typically constrain the use of bioretention, although they do determine whether an underdrain is needed. Underdrains may be required if the measured permeability of the underlying soils is less than 0.5 in./hr. When designing a bioretention practice, designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix O. Impermeable soils will require an underdrain.

For fill soil locations, geotechnical investigations are required to determine if it is necessary to use an impermeable liner and underdrain.

Contributing Drainage Area. Bioretention cells work best with smaller CDAs, where it is easier to achieve flow distribution over the filter bed. The maximum drainage area to a traditional bioretention area (B-1) is 2.5 acres and can consist of up to 100 percent impervious cover. The drainage area for smaller bioretention practices (B-2, B-3, B-4, and B-5) is a maximum of 1 acre. However, if hydraulic considerations are adequately addressed to manage the potentially large peak inflow of larger drainage areas, such as off-line or low-flow diversions, or forebays, there may be case-by-case instances where the maximum drainage areas can be adjusted. Table 3.18 summarizes typical recommendations for bioretention CDAs.

Table 3.18 Maximum Contributing Drainage Area to Bioretention

Bioretention Type	Design Variants	Maximum Contributing Drainage Area (acres of impervious cover)
Traditional	B-1	2.5
Small-scale and urban bioretention	B-2, B-3, B-4, and B-5	1.0

Hotspot Land Uses. An impermeable bottom liner and an underdrain system must be employed when a bioretention area will receive untreated hotspot runoff, and the Enhanced Design configuration cannot be used. However, bioretention can still be used to treat parts of the site that are outside of the hotspot area. For instance, roof runoff can go to bioretention while vehicular maintenance areas would be treated by a more appropriate hotspot practice.

For a list of potential stormwater hotspots, please consult Appendix P.

On sites with existing contaminated soils, as indicated in Appendix P, infiltration is not allowed. Bioretention areas must include an impermeable liner, and the Enhanced Design configuration cannot be used.

No Irrigation or Baseflow. The planned bioretention area should not receive baseflow, irrigation water, chlorinated wash-water or any other flows not related to stormwater. However, irrigation is allowed during the establishment period of the bioretention area to ensure plant survival.

Setbacks. To avoid the risk of seepage, bioretention areas must not be hydraulically connected to structure foundations. Setbacks to structures must be at least 10 feet and adequate water-proofing protection must be provided for foundations and basements. Where the 10-foot setback is not possible, an impermeable liner may be used along the sides of the bioretention area (extending from the surface to the bottom of the practice).

Proximity to Utilities. Designers should ensure that future tree canopy growth in the bioretention area will not interfere with existing overhead utility lines. Interference with underground utilities should be avoided, if possible. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the public right-of-way. Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the bioretention system. For bioretention in the public right-of-way a consolidated presentation of the various utility offset recommendations can be found in Chapter 33.14.5 of the District of Columbia Department of Transportation Design and Engineering Manual, latest edition. Consult the District of Columbia Water and Sewer Authority (DC Water) Green Infrastructure Utility Protection Guidelines, latest edition, for water and sewer line recommendations. Where conflicts cannot be avoided, follow these guidelines:

- Consider altering the location or sizing of the bioretention to avoid or minimize the utility conflict. Consider an alternate BMP type to avoid conflict.
- Use design features to mitigate the impacts of conflicts that may arise by allowing the bioretention and the utility to coexist. The bioretention design may need to incorporate impervious areas, through geotextiles or compaction, to protect utility crossings. Other a key design feature may need to be moved or added or deleted
- Work with the utility to evaluate the relocation of the existing utility and install the optimum placement and sizing of the bioretention.
- If utility functionality, longevity and vehicular access to manholes can be assured accept the bioretention design and location with the existing utility. Incorporate into the bioretention design sufficient soil coverage over the utility or general clearances or other features such as an impermeable linear to assure all entities the conflict is limited to maintenance.

Note: When accepting utility conflict into the bioretention location and design, it is understood the bioretention will be temporarily impacted during utility work but the utility will replace the bioretention or, alternatively, install a functionally comparable bioretention according to the specifications in the current version of this Stormwater Management Guidebook. If the bioretention is located in the public right-of-way the bioretention restoration will also conform with the District of Columbia Department of Transportation Design and Engineering Manual with special attention to Chapter 33, Chapter 47, and the Design and Engineering Manual supplements for Low Impact Development and Green Infrastructure Standards and Specifications.

Minimizing External Impacts. Urban bioretention practices may be subject to higher public visibility, greater trash loads, pedestrian traffic, vandalism, and even vehicular loads. Designers should design these practices in ways that prevent, or at least minimize, such impacts. In addition, designers should clearly recognize the need to perform frequent landscaping maintenance to remove trash, check for clogging, and maintain vigorous vegetation. The urban landscape context may feature naturalized landscaping or a more formal design. When urban bioretention is used in sidewalk areas of high foot traffic, designers should not impede pedestrian movement or create a safety hazard. Designers may also install low fences, grates, or other measures to prevent damage from pedestrian short-cutting across the practices.

When bioretention will be included in public rights-of-way or spaces, design manuals and guidance developed by agencies or organizations other than DDOE may also apply (e.g., District Department of Transportation, Office of Planning, and National Capital Planning Commission).

3.6.2 Bioretention Conveyance Criteria

There are two basic design approaches for conveying runoff into, through, and around bioretention practices:

1. Off-line: Flow is split or diverted so that only the design storm or design flow enters the bioretention area. Larger flows bypass the bioretention treatment.
2. On-line: All runoff from the drainage area flows into the practice. Flows that exceed the design capacity exit the practice via an overflow structure or weir.

If runoff is delivered by a storm drain pipe or is along the main conveyance system, the bioretention area shall be designed off-line so that flows to do not overwhelm or damage the practice.

Off-line Bioretention. Overflows are diverted from entering the bioretention cell. Optional diversion methods include the following:

- 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 filters through the soil media. With this design configuration, an overflow structure in the bioretention area is not required.
- Utilize a low-flow diversion or flow splitter at the inlet to allow only the design storm volume (i.e., the Stormwater Retention Volume (SWRv)) to enter the facility (calculations must be made to determine the peak flow from the 1.2-inch, 24-hour storm). This may be achieved with a weir, curb opening, or orifice for the target flow, in combination with a bypass channel or pipe. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency. With this design configuration, an overflow structure in the bioretention area is required (see on-line bioretention below).

On-line Bioretention. An overflow structure must be incorporated into on-line designs to safely convey larger storms through the bioretention area. The following criteria apply to overflow structures:

- An overflow shall be provided within the practice to pass storms greater than the design storm storage to a stabilized water course. A portion of larger events may be managed by the bioretention area so long as the maximum depth of ponding in the bioretention cell does not exceed 18 inches.
- The overflow device must convey runoff to a storm sewer, stream, or the existing stormwater conveyance infrastructure, such as curb and gutter or an existing channel.

- Common overflow systems within bioretention practices consist of an inlet structure, where the top of the structure is placed at the maximum ponding depth of the bioretention area, which is typically 6 to 18 inches above the surface of the filter bed.
- The overflow device should be scaled to the application. This may be a landscape grate or yard inlet for small practices or a commercial-type structure for larger installations.
- At least 3–6 inches of freeboard must be provided between the top of the overflow device and the top of the bioretention area to ensure that nuisance flooding will not occur.
- The overflow associated with the 2-year and 15-year design storms must be controlled so that velocities are non-erosive at the outlet point, to prevent downstream erosion.

3.6.3 Bioretention Pretreatment Criteria

Pretreatment of runoff entering bioretention areas is necessary to trap coarse sediment particles before they reach and prematurely clog the filter bed. Pretreatment measures must be designed to evenly spread runoff across the entire width of the bioretention area. Several pretreatment measures are feasible, depending on the type of the bioretention practice and whether it receives sheet flow, shallow concentrated flow, or deeper concentrated flows. The following are appropriate pretreatment options:

Small-Scale Bioretention (B-2, B-3, B-4, and B-5)

- **Leaf Screens**. A leaf screen serves as part of the gutter system to keep the heavy loading of organic debris from accumulating in the bioretention cell.
- **Pretreatment Cells** (for channel flow). Pretreatment cells are located above ground or covered by a manhole or grate. Pretreatment cells are atypical in small-scale bioretention and are not recommended for residential rain gardens (B-5).
- **Grass Filter Strips** (for sheet flow). Grass filter strips are applied on residential lots, where the lawn area can serve as a grass filter strip adjacent to a rain garden.
- **Stone Diaphragm** (for either sheet flow or concentrated flow). The stone diaphragm at the end of a downspout or other concentrated inflow point should run perpendicular to the flow path to promote settling.

  Note: stone diaphragms are not recommended for school settings.
- **Trash Racks** (for either sheet flow or concentrated flow).Trash racks are located between the pretreatment cell and the main filter bed or across curb cuts to allow trash to collect in specific locations and make maintenance easier.

Traditional Bioretention (B-1)

- **Pretreatment Cells** (for channel flow). Similar to a forebay, this cell is located at piped inlets or curb cuts leading to the bioretention area and consists of an energy dissipater sized for the expected rates of discharge. It has a storage volume equivalent to at least 15 percent of the total storage volume (inclusive) with a recommended 2:1 length-to-width ratio. The cell may be formed by a wooden or stone check dam or an earthen or rock berm. Pretreatment cells do not need underlying engineered soil media, in contrast to the main bioretention cell. However, if the volume of the pretreatment cell will be included as part of the bioretention storage volume, the pretreatment cell must de-water between storm events. It cannot have a permanent ponded volume.

- **Grass Filter Strips** (for sheet flow). Grass filter strips that are perpendicular to incoming sheet flow extend from the edge of pavement, with a slight drop at the pavement edge, to the bottom of the bioretention basin at a 5:1 slope or flatter. Alternatively, if the bioretention basin has side slopes that are 3:1 or flatter, a 5-foot grass filter strip can be used at a maximum 5 percent (20:1) slope.
- **Stone Diaphragms** (for sheet flow). A stone diaphragm located at the edge of the pavement should be oriented perpendicular to the flow path to pretreat lateral runoff, with a 2 to 4 inch drop from the pavement edge to the top of the stone. The stone must be sized according to the expected rate of discharge.
- **Gravel or Stone Flow Spreaders** (for concentrated flow). The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2 to 4 inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel must extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the basin.
- **Filter System** (see Section 3.7 Stormwater Filtering Systems). If using a filter system as a pretreatment facility, the filter will not require a separate pretreatment facility.
- **Innovative or Proprietary Structure**. An approved proprietary structure with demonstrated capability of reducing sediment and hydrocarbons may be used to provide pretreatment. Refer to Section 3.13 Proprietary Practices for information on approved proprietary structures.

Other pretreatment options may be appropriate as long as they trap coarse sediment particles and evenly spread runoff across the entire width of the bioretention area.

3.6.4 Bioretention Design Criteria

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

Inlets and Energy Dissipation. Where appropriate, the inlet(s) to streetscape bioretention (B-2), engineered tree boxes (B-3), and stormwater planters (B-4) should be stabilized using No. 3 stone, splash block, river stone, or other acceptable energy dissipation measures. The following types of inlets are recommended:

- Downspouts to stone energy dissipaters.
- Sheet flow over a depressed curb with a 3-inch drop.
- Curb cuts allowing runoff into the bioretention area.

- Covered drains that convey flows across sidewalks from the curb or downspouts.
- Grates or trench drains that capture runoff from a sidewalk or plaza area.
- Drop structures that appropriately dissipate water energy.

Ponding Depth. The recommended surface ponding depth is 6–12 inches. Minimum surface ponding depth is 3 inches (averaged over the surface area of the BMP). Ponding depths can be increased to a maximum of 18 inches. However, when higher ponding depths are utilized, the design must consider carefully issues such as safety, fencing requirements, aesthetics, the viability and survival of plants, and erosion and scour of side slopes. This is especially true where bioretention areas are built next to sidewalks or other areas were pedestrians or bicyclists travel. Shallower ponding depths (typically 6–12 inches) are recommended for streetscape bioretention (B-2), engineered tree boxes (B-3), and stormwater planters (B-4).

Side Slopes. Traditional bioretention areas (B-1) and residential rain gardens (B-5) should be constructed with side slopes of 3:1 or flatter. In highly urbanized or space constrained areas, a drop curb design or a precast structure can be used to create a stable, vertical side wall. These drop curb designs should not exceed a vertical drop of more than 12 inches, unless safety precautions, such as railings, walls, grates, etc. are included.

Filter Media. The filter media and surface cover are the two most important elements of a bioretention facility in terms of long-term performance.

- **Particle Size Composition.** The bioretention soil mixture shall be classified as a loamy sand on the USDA Texture Triangle, with the following particle size composition:
    - 80–90 percent sand (at least 75 percent of which must be classified as coarse or very coarse sand)
    - 10–20 percent soil fines (silt and clay)
    - Maximum 10 percent clay
    - The particle size analysis must be conducted on the mineral fraction only or following appropriate treatments to remove organic matter before particle size analysis.
- **Organic Matter.** The filter media must contain 3 to 5 percent organic matter by the conventional Walkley-Black soil organic matter determination method or similar analysis. Soil organic matter is expressed on a dry weight basis and does not include coarse particulate (visible) components.
- **Available Soil Phosphorus (P).** The filter media should contain sufficient available P to support initial plant establishment and growth, but not serve as a significant source of P for long-term leaching. Plant-available soil P should be within the range of Low+ (L+) to Medium (M) as defined in Table 2.2 of Virginia Nutrient Management Standards and Criteria (2005). For the Mehlich I extraction procedure this equates to a range of 5 to 15 mg/kg P or 18 to 40 mg/kg P for the Mehlich III procedure.
- **Cation Exchange Capacity (CEC).** The relative ability of soils to hold and retain nutrient cations like Ca and K is referred to as cation exchange capacity (CEC) and is measured as the total amount of positively charged cations that a soil can hold per unit dry mass. CEC is also

used as an index of overall soil reactivity and is commonly expressed in milliequivalents per 100 grams (meq/100g) of soil or cmol+/kg (equal values). A soil with a moderate to high CEC indicates a greater ability to capture and retain positively charged contaminants, which encourages conditions to remove phosphorus, assuming that soil fines (particularly fine silts and clays) are at least partially responsible for CEC. The minimum CEC of the filter media is 5.0 (meq/100 g or cmol+/kg). The filter media CEC should be determined by the Unbuffered Salt, Ammonium Acetate, Summation of Cations or Effective CEC techniques (Sumner and Miller, 1996) or similar methods that do not utilize strongly acidic extracting solutions.

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

The following is the recommended composition of the three media ingredients:

- **Sand.** Sand shall consist of silica-based coarse aggregate, angular or round in shape and meet the mixture grain size distribution specified in Table 3.19. No substitutions of alternate materials (such as diabase, calcium carbonate, rock dust, or dolomitic sands) are accepted. In particular, mica can make up no more than 5 percent of the total sand fraction. The sand fraction may also contain a limited amount of particles greater than 2.0 mm and less than 9.5 mm per the table below, but the overall sand fraction must meet the specification containing greater than 75 percent coarse or very coarse sand. Consult Table 3.19 for recommended sand sizing criteria.

Table 3.19 Sand Sizing Criteria

Sieve Type	Particle Size (mm)	Percent Passing (%)
3/8 in.	9.50	100
No. 4	4.75	95– 100
No. 8	2.36	80– 100
No. 16	1.18	45– 85
No. 30	0.60	15– 60
No. 50	0.30	3– 15
No. 100	0.15	0– 4

Note: Effective particle size (D10) > 0.3mm. Uniformity coefficient (D60/D10) < 4.0.

- **Topsoil.** Topsoil is generally defined as the combination of the ingredients referenced in the bioretention filter media: sand, fines (silt and clay), and any associated soil organic matter. Since the objective of the specification is to carefully establish the proper blend of these ingredients, the designer (or contractor or materials supplier) must carefully select the topsoil source material in order to not exceed the amount of any one ingredient.

Generally, the use of a topsoil defined as a loamy sand, sandy loam, or loam (per the USDA Textural Triangle) will be an acceptable ingredient and in combination with the other ingredients meet the overall performance goal of the soil media.

- **Organic Matter.** Organic materials used in the soil media mix should consist of well-decomposed natural C-containing organic materials such as peat moss, humus, compost (consistent with the material specifications found in Appendix J), pine bark fines or other organic soil conditioning material. However, per above, the combined filter media should contain 3 to 5 percent soil organic matter on dry weight basis (grams organic matter per 100 grams dry soil) by the Walkley-Black method or other similar analytical technique.

  In creating the filter media, it is recommended to start with an open-graded coarse sand material and proportionately mix in the topsoil materials to achieve the desired ratio of sand and fines. Sufficient suitable organic amendments can then be added to achieve the 3 to 5 percent soil organic matter target. The exact composition of organic matter and topsoil material will vary, making the exact particle size distribution of the final total soil media mixture difficult to define in advance of evaluating available materials. Table 3.20 summarizes the filter media requirements.

Table 3.20 Filter Media Criteria for Bioretention

<table>
<tr><th>Soil Media Criterion</th><th>Description</th><th colspan="3">Standard(s)</th></tr>
<tr><td>General Composition</td><td>Soil media must have the proper proportions of sand, fines, and organic matter to promote plant growth, drain at the proper rate, and filter pollutants</td><td colspan="3">80% to 90% sand
(75% of which is coarse or very coarse);
10% to 20% soil fines;
maximum of 10% clay; and
3% to 5% organic matter</td></tr>
<tr><td rowspan="2">Sand</td><td rowspan="2">Silica based coarse aggregate[1]</td><td>Sieve Type

3/8 in.
No. 4
No. 8
No. 16
No. 30
No. 50
No. 100</td><td>Particle Size (mm)
9.50
4.75
2.36
1.18
0.6
0.3
0.15</td><td>Percent Passing (%)
100
95–100
80–100
45–85
15–60
3–15
0–4</td></tr>
<tr><td colspan="3">Effective Particle size (D10) > 0.3mm
Uniformity Coefficient (D60/D10) < 4.0</td></tr>
<tr><td>Top Soil</td><td>Loamy sand or sandy loam</td><td colspan="3">USDA Textural Triangle</td></tr>
<tr><td>Organic Matter</td><td>Well-aged, clean compost</td><td colspan="3">Appendix J</td></tr>
<tr><td>P-Index or Phosphorus (P) Content</td><td>Soil media with high P levels will export P through the media and potentially to downstream conveyances or receiving waters</td><td colspan="3">P content = 5 to 15 mg/kg (Mehlich I) or 18 to 40 mg/kg (Mehlich III)</td></tr>
<tr><td>Cation Exchange Capacity (CEC)</td><td>The CEC is determined by the amount of soil fines and organic matter. Higher CEC will promote pollutant removal</td><td colspan="3">CEC > 5 milliequivalents per 100 grams</td></tr>
</table>

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

In cases where greater removal of specific pollutants is desired, additives with documented pollutant removal benefits, such as water treatment residuals, alum, iron, or other materials may be included in the filter media if accepted by DDOE.

- **Filter Media Depth.** The filter media bed depth must be a minimum of 18 inches for the Standard Design. The media depth must be 24 inches or greater to qualify for the Enhanced Design, unless an infiltration-based design is used. The media depth must not exceed 6 feet. Turf, perennials, or shrubs should be used instead of trees to landscape shallower filter beds. See Table 3.23 and Table 3.24 for a list of recommended native plants.

During high intensity storm events, it is possible for the bioretention to fill up faster than the collected stormwater is able to filter through the soil media. This is dependent upon the surface area of the BMP (*SA*) relative to the contributing drainage area (CDA) and the runoff coefficient (*Rv*) from the CDA. To ensure that the design runoff volume is captured and filtered appropriately, a maximum filter media depth must not be exceeded (see Table 3.24). The maximum filter media depth is based on the runoff coefficient of the CDA to the BMP (Rv_{CDA}) and the bioretention ratio of BMP surface area to the BMP CDA (SA:CDA) (in percent). The applicable filter media depth from Table 3.21 should be used as d_{media} in Equation 3.5.

Table 3.21 Determining Maximum Filter Media Depth (feet)

SA:CDA (%)	**RvCDA**								
	0.25	**0.3**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**0.95**
0.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
1.0	5.0	5.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
1.5	3.5	4.0	5.0	6.0	6.0	6.0	6.0	6.0	6.0
2.0	2.5	3.0	4.0	5.0	5.5	6.0	6.0	6.0	6.0
2.5	2.0	2.5	3.5	4.0	4.5	5.0	5.5	6.0	6.0
3.0	1.5	2.0	3.0	3.5	4.0	4.5	5.0	5.5	5.5
3.5	1.5	1.5	2.5	3.0	3.5	4.0	4.5	5.0	5.0
4.0	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.5	4.5
4.5	1.5	1.5	2.0	2.5	3.0	3.5	3.5	4.0	4.5
5.0	1.5	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.0
5.5	1.5	1.5	1.5	2.0	2.5	2.5	3.0	3.5	3.5
6.0	1.5	1.5	1.5	1.5	2.0	2.5	3.0	3.0	3.5
6.5	1.5	1.5	1.5	1.5	2.0	2.5	2.5	3.0	3.0
7.0	1.5	1.5	1.5	1.5	1.5	2.0	2.5	3.0	3.0
7.5	1.5	1.5	1.5	1.5	1.5	2.0	2.5	2.5	2.5
8.0	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.5	2.5
8.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.5
9.0	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.0
9.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0
10.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0

Surface Cover. Mulch is the recommended surface cover material, but other materials may be substituted, as described below:

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

- Alternative to Mulch Cover. In some situations, designers may consider alternative surface covers, such as turf, native groundcover, erosion control matting (e.g., coir or jute matting), river stone, or pea gravel. The decision regarding the type of surface cover to use should be based on function, expected pedestrian traffic, cost, and maintenance. When alternative surface covers are used, methods to discourage pedestrian traffic should be considered. Stone or gravel are not recommended in parking lot applications, since they increase soil temperature and have low water-holding capacity.
- Media for Turf Cover. One adaptation suggested for use with turf cover is to design the filter media primarily as a sand filter with organic content only at the top. Compost, as specified in Appendix J, tilled into the top layers will provide organic content for the vegetative cover. If grass is the only vegetation, the ratio of organic matter in the filter media composition may be reduced.

Choking Layer. A 2 to 4 inch layer of choker stone (e.g., typically ASTM D448 No. 8 or No. 89 washed gravel) should be placed beneath the soil media and over the underdrain stone.

Geotextile. If the available head is limited, or the depth of the practice is a concern, geotextile fabric may be used in place of the choking layer. An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements, and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used. Geotextile fabric may be used on the sides of bioretention areas, as well.

Underdrains. Many bioretention designs will require an underdrain (see Section 3.6.1 Bioretention Feasibility Criteria). The underdrain should be a 4- or 6-inch perforated schedule 40 PVC pipe, or equivalent corrugated HDPE for small bioretention BMPs, with 3/8-inch perforations at 6 inches on center. The underdrain must be encased in a layer of clean, double washed ASTM D448 No.57 or smaller (No. 68, 8, or 89) stone. The underdrain must be sized so that the bioretention BMP fully drains within 72 hours or less.

Multiple underdrains are necessary for bioretention areas wider than 40 feet, and each underdrain must be located no more than 20 feet from the next pipe or the edge of the bioretention. (For long and narrow applications, a single underdrain running the length of the bioretention is sufficient.)

All traditional bioretention practices must include at least one observation well and/or cleanout pipe (minimum 4 inches in diameter). The observation wells should be tied into any of the Ts or Ys in the underdrain system and must extend upward above the surface of the bioretention area.

Underground Storage Layer (optional). For bioretention systems with an underdrain, an underground storage layer consisting of chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer and underdrain to increase the infiltration sump volume or the storage for larger storm events. To qualify for the Enhanced Design, this storage layer must be designed to infiltrate in 72 hours, at ½ the measured infiltration rate. The may also be designed to provide detention for the 2-year, 15-year, or 100-year storms, as needed. The depth and volume of the storage layer will then depend on the target storage volumes needed to meet the applicable detention criteria.

Impermeable Liner. An impermeable liner is not typically required, although it may be utilized in fill applications where deemed necessary by a geotechnical investigation, on sites with contaminated soils, or on the sides of the practice to protect adjacent structures from seepage. Use a 30-mililiter (minimum) PVC geomembrane liner. (Follow manufacturer's instructions for installation.) Field seams must be sealed according to the liner manufacturer's specifications. A minimum 6-inch overlap of material is required at all seams.

Material Specifications. Recommended material specifications for bioretention areas are shown in Table 3.22.

Table 3.22 Bioretention Material Specifications

Material	Specification	Notes
Filter Media	▪ See Table 3.20	Minimum depth of 24 inches (18 inches for small-scale practices) To account for settling/compaction, it is recommended that 110% of the plan volume be utilized.
Mulch Layer	Use aged, shredded hardwood bark mulch	Lay a 2 to 3-inch layer on the surface of the filter bed.
Alternative Surface Cover	Use river stone or pea gravel, coir and jute matting, or turf cover.	Lay a 2 to 3-inch layer of to suppress weed growth.
Top Soil For Turf Cover	Loamy sand or sandy loam texture, with less than 5% clay content, pH corrected to between 6 and 7, and an organic matter content of at least 2%.	3-inch tilled into surface layer.
Geotextile or Choking Layer	An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used	Can use in place of the choking layer where the depth of the practice is limited. Geotextile fabric may be used on the sides of bioretention areas, as well.
	Lay a 2 to 4 inch layer of choker stone (e.g., typically No.8 or No.89 washed gravel) over the underdrain stone.	
Underdrain stone	1-inch diameter stone must be double-washed and clean and free of all fines (e.g., ASTM D448 No. 57 or smaller stone).	At least 2 inches above and below the underdrain.
Storage Layer (optional)	To increase storage for larger storm events, chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer	
Impermeable Liner (optional)	Where appropriate, use a thirty mil (minimum) PVC Geomembrane liner	
Underdrains, Cleanouts, and Observation Wells	Use 4- or 6-inch rigid schedule 40 PVC pipe, or equivalent corrugated HDPE for small bioretention BMPs, with 3/8-inch perforations at 6 inches on center. Multiple underdrains are necessary for bioretention areas wider than 40 feet, and each underdrain must be located no more than 20 feet from the next pipe or the edge of the bioretention.	Lay the perforated pipe under the length of the bioretention cell, and install non-perforated pipe as needed to connect with the storm drain system or to daylight in a stabilized conveyance. Install T's and Y's as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface.

Material	Specification	Notes
Plant Materials	See Section 3.6.5 Bioretention Landscaping Criteria	Establish plant materials as specified in the landscaping plan and the recommended plant list.

Signage. Bioretention units in highly urbanized areas should be stenciled or otherwise permanently marked to designate it as a structural BMP. The stencil or plaque should indicate (1) its water quality purpose, (2) that it may pond briefly after a storm, and (3) that it is not to be disturbed except for required maintenance.

Specific Design Issues for Streetscape Bioretention (B-2). Streetscape bioretention is installed in the road right-of way either in the sidewalk area or in the road itself. In many cases, streetscape bioretention areas can also serve as a traffic calming or street parking control devices. The basic design adaptation is to move the raised concrete curb closer to the street or in the street, and then create inlets or curb cuts that divert street runoff into depressed vegetated areas within the right-of-way. Roadway stability can be a design issue where streetscape bioretention practices are installed. Designers should consult design standards pertaining to roadway drainage. It may be necessary to provide an impermeable liner on the road side of the bioretention area to keep water from saturating the road's sub-base.

Specific Design Issues for Engineered Tree Boxes (B-3). Engineered tree boxes are installed in the sidewalk zone near the street where urban street trees are normally installed. The soil volume for the tree pit is increased and used to capture and treat stormwater. Treatment is increased by using a series of connected tree planting areas together in a row. The surface of the enlarged planting area may be mulch, grates, permeable pavers, or conventional pavement. The large and shared rooting space and a reliable water supply increase the growth and survival rates in this otherwise harsh planting environment.

When designing engineered tree boxes, the following criteria must be considered:

- The bottom of the soil layer must be a minimum of 4 inches below the root ball of plants to be installed.
- Engineered tree box designs sometimes cover portions of the filter media with pervious pavers or cantilevered sidewalks. In these situations, it is important that the filter media is connected beneath the surface so that stormwater and tree roots can share this space.
- Installing an engineered tree pit grate over filter bed media is one possible solution to prevent pedestrian traffic and trash accumulation.
- Low, wrought iron fences can help restrict pedestrian traffic across the tree pit bed and serve as a protective barrier if there is a drop-off from the pavement to the micro-bioretention cell.
- A removable grate may be used to allow the tree to grow through it.
- Each tree needs a minimum rootable soil volume as described in Section 3.14.

Specific Design Issues for Stormwater Planters (B-4). Stormwater planters are a useful option to disconnect and treat rooftop runoff, particularly in ultra-urban areas. They consist of confined planters that store and/or infiltrate runoff in a soil bed to reduce runoff volumes and pollutant loads. Stormwater planters combine an aesthetic landscaping feature with a functional form of stormwater treatment. Stormwater planters generally receive runoff from adjacent rooftop downspouts and are landscaped with plants that are tolerant to periods of both drought and inundation. The two basic design variations for stormwater planters are the infiltration planter and the filter planter. A filter planter is illustrated in Figure 3.2 below.

An infiltration planter filters rooftop runoff through soil in the planter followed by infiltration into soils below the planter. The minimum filter media depth is 18 inches, with the shape and length determined by architectural considerations. Infiltration planters should be placed at least 10 feet away from a building to prevent possible flooding or basement seepage damage.

A filter planter does not allow for infiltration and is constructed with a watertight concrete shell or an impermeable liner on the bottom to prevent seepage. Since a filter planter is self-contained and does not infiltrate into the ground, it can be installed right next to a building. The minimum filter media depth is 18 inches, with the shape and length determined by architectural considerations. Runoff is captured and temporarily ponded above the planter bed. Overflow pipes are installed to discharge runoff when maximum ponding depths are exceeded, to avoid water spilling over the side of the planter. In addition, an underdrain is used to carry runoff to the storm sewer system.

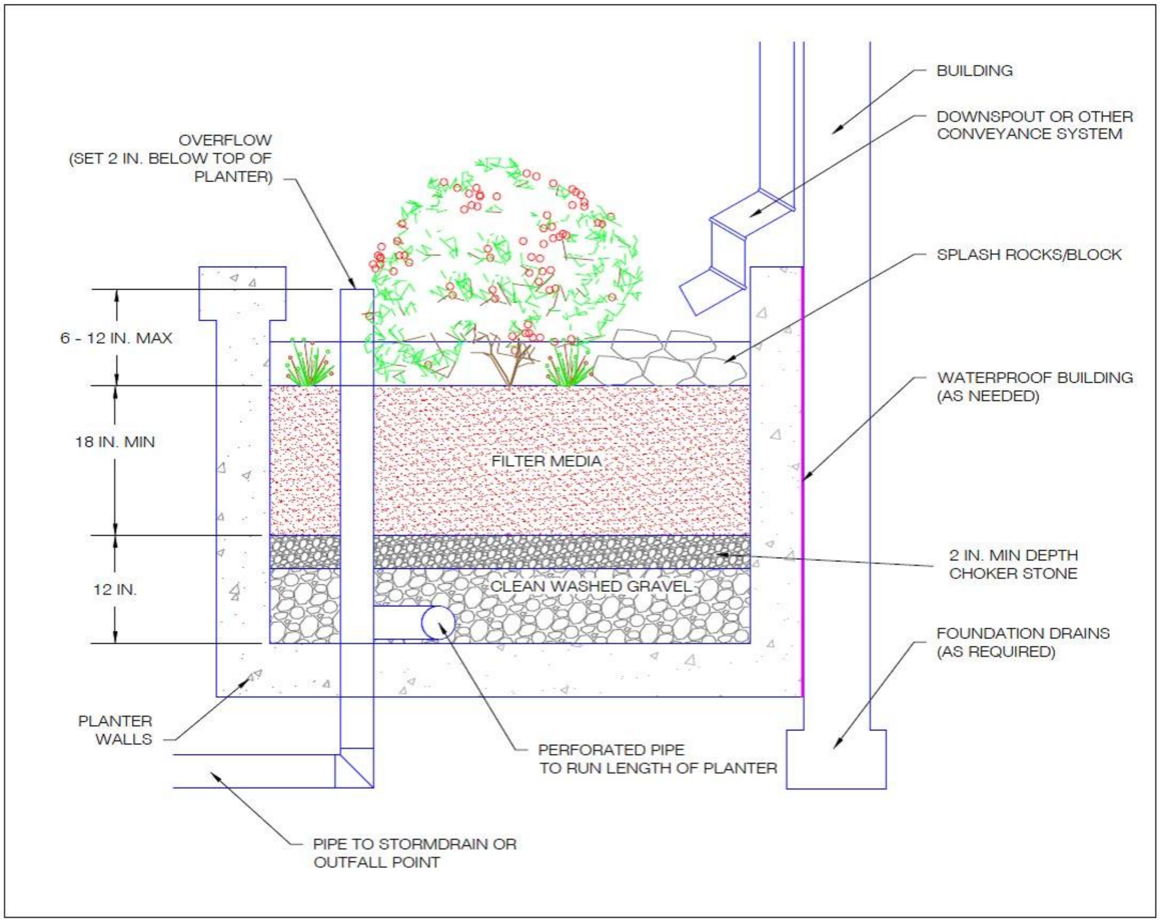

Figure 3.20 Example of a stormwater planter (B-4).

All planters should be placed at grade level or above ground. Plant materials must be capable of withstanding moist and seasonally dry conditions. The sand and gravel on the bottom of the planter should have a minimum infiltration rate of 5 inches per hour. The planter can be constructed of stone, concrete, brick, wood, or other durable material. If treated wood is used, care should be taken so that trace metals and creosote do not leach out of the planter.

Specific Design Issues for Residential Rain Gardens (B-5). For some residential applications, front, side, and/or rear yard bioretention may be an attractive option. This form of bioretention captures roof, lawn, and driveway runoff from low- to medium- density residential lots in a depressed area (i.e., 6 to 12 inches) between the home and the primary stormwater conveyance system (i.e., roadside ditch or pipe system). The bioretention area connects to the drainage system with an underdrain.

The bioretention filter media must be at least 18 inches deep. The underdrain is directly connected into the storm drain pipe running underneath the street or in the street right-of-way. A trench needs to be excavated during construction to connect the underdrain to the street storm drain system.

Construction of the remainder of the bioretention system is deferred until after the lot has been stabilized. Residential rain gardens require regular maintenance to perform effectively.

BMP Sizing. Bioretention is typically sized to capture the SWRv or larger design storm volumes in the surface ponding area, soil media, and gravel reservoir layers of the BMP.

Total storage volume of the BMP is calculated using Equation 3.5.

Equation 3.5 Bioretention Storage Volume

$$Sv = SA_{bottom} \times [(d_{media} \times \eta_{media}) + (d_{gravel} \times \eta_{gravel})] + (SA_{average} \times d_{ponding})$$

where:

Sv	=	total storage volume of bioretention (ft^3)
SA_{bottom}	=	bottom surface area of bioretention (ft^2)
d_{media}	=	depth of the filter media (ft)
η_{media}	=	effective porosity of the filter media (typically 0.25)
d_{gravel}	=	depth of the underdrain and underground storage gravel layer (ft)
η_{gravel}	=	effective porosity of the gravel layer (typically 0.4)
$SA_{average}$	=	average surface area of bioretention (ft^2) typically, where SA_{top} is the top surface area of bioretention, $SA_{average} = \frac{SA_{bottom} + SA_{top}}{2}$
$d_{ponding}$	=	maximum ponding depth of bioretention (ft)

Equation 3.5 can be modified if the storage depths of the filter media, gravel layer, or ponded water vary in the actual design or with the addition of any surface or subsurface storage components (e.g., additional area of surface ponding, subsurface storage chambers, etc.). The maximum depth of ponding in the bioretention must not exceed 18 inches. If storage practices will be provided off-line or in series with the bioretention area, the storage practices should be sized using the guidance in Section 3.12.

Bioretention can be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The *Sv* can be counted as part of the 2-year or 15-year runoff volumes to satisfy stormwater quantity control requirements. At least 3–6 inches of freeboard are required between the top of the overflow device and the top of the bioretention area when bioretention is used as detention storage for 2-year and 15-year storms.

Note: In order to increase the storage volume of a bioretention area, the ponding surface area may be increased beyond the filter media surface area. However, the top surface area of the practice (i.e., at the top of the ponding elevation) may not be more than twice the size of the surface area of the filter media (SA_{bottom}).

3.6.5 Bioretention Landscaping Criteria

Landscaping is critical to the performance and function of bioretention areas. Therefore, a landscaping plan shall be provided for bioretention areas.

Minimum plan elements include the proposed bioretention template to be used, delineation of planting areas, and the planting plan including the following:

- Common and botanical names of the plants used
- Size of planted materials
- Mature size of the plants
- Light requirements
- Maintenance requirements
- Source of planting stock
- Any other specifications
- Planting sequence

It is recommended that the planting plan be prepared by a qualified landscape architect professional (e.g. licensed professional landscape architect, certified horticulturalist) in order to tailor the planting plan to the site-specific conditions.

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. Some popular native species that work well in bioretention areas and are commercially available can be found in Table 3.23 and Table 3.24. Internet links to more detailed bioretention plant lists developed in the Chesapeake Bay region are provided below:

- Prince Georges County, MD
  http://www.aacounty.org/DPW/Highways/Resources/Raingarden/RG_Bioretention_PG%20CO.pdf
- Delaware Green Technology Standards and Specifications
  http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20&%20Specs_06-05.pdf

The degree of landscape maintenance that can be provided will determine some of the planting choices for urban bioretention areas. Plant selection differs if the area will be frequently mowed, pruned, and weeded, in contrast to a site which will receive minimum annual maintenance. In areas where less maintenance will be provided and where trash accumulation in shrubbery or herbaceous plants is a concern, consider a “turf and trees” landscaping model where the turf is mowed along with other turf areas on the site. Spaces for herbaceous flowering plants can be included.

Table 3.23 Herbaceous Plants Appropriate for Bioretention Areas in the District

Plant	Light	Wetland Indicator[1]	Plant Form	Inundation Tolerance	Notes
Aster, New York (*Aster novi-belgii*)	Full Sun-Part Shade	FACW+	Perennial	Yes	Attractive flowers; tolerates poor soils
Aster, New England (*Aster novae-angliae*)	Full Sun-Part Shade	FACW	Perennial	Yes	Attractive flowers
Aster, Perennial Saltmarsh (*Aster tenuifolius*)	Full Sun-Part Shade	OBL	Perennial	Yes	Salt tolerant
Coreopsis, Threadleaf (*Coreopsis verticillata*)	Full Sun-Part Shade	FAC	Perennial	No	Drought tolerant
Beardtongue (*Penstemon digitalis*)	Full Sun	FAC	Perennial	No	Tolerates poor drainage
Beebalm (*Monarda didyma*)	Full Sun-Part Shade	FAC+	Perennial	Saturated	Herbal uses; attractive flower
Black-Eyed Susan (*Rudbeckia hirta*)	Full Sun-Part Shade	FACU	Perennial	No	Common; Maryland state flower
Bluebells, Virginia (*Mertensia virginica*)	Part Shade-Full Shade	FACW	Perennial	Yes	Attractive flower; dormant in summer
Blueflag,Virginia (*Iris virginica*)	Full Sun-Part Shade	OBL	Perennial	Yes	Tolerates standing water
Bluestem, Big (*Andropogon gerardii*)	Full Sun	FAC	Grass	No	Attractive in winter; forms clumps
Bluestem, Little (*Schizachyrium scoparium*)	Full Sun	FACU	Grass	No	Tolerates poor soil conditions
Broom-Sedge (Andropogon virginicus)	Full Sun	FACU	Grass	No	Drought tolerant; attractive fall color
Cardinal Flower (*Lobelia cardinalis*)	Full Sun-Part Shade	FACW+	Perennial	Yes	Long boom time
Fern, New York (*Thelypteris noveboracensis*)	Part Shade-Full Shade	FAC	Fern	Saturated	Drought tolerant; spreads
Fern, Royal (*Osmunda regalis*)	Full Sun-Full Shade	OBL	Fern	Saturated	Tolerates short term flooding; drought tolerant
Fescue, Red (*Festuca rubra*)	Full Sun-Full Shade	FACU	Ground-cover	No	Moderate growth; good for erosion control
Iris, Blue Water (*Iris versicolor*)	Full Sun-Part Shade	OBL	Perennial	0-6"	Spreads
Lobelia, Great Blue (*Lobelia siphilitica*)	Part Shade-Full Shade	FACW+	Perennial	Yes	Blooms in late summer; bright blue flowers
Phlox, Meadow (*Phlox maculata*)	Full Sun	FACW	Perennial	Yes	Aromatic; spreads
Sea-Oats (*Uniola paniculata*)	Full Sun	FACU-	Grass	No	Salt tolerant; attractive seed heads
Swamp Milkweed (*Asclepias incarnata*)	Full Sun-Part Shade	OBL	Perennial	Saturated	Drought tolerant
Switchgrass (*Panicum virgatum*)	Full Sun	FAC	Grass	Seasonal	Adaptable; great erosion control

Plant	Light	Wetland Indicator[1]	Plant Form	Inundation Tolerance	Notes
Turtlehead, White (*Chelone glabra*)	Full Sun-Part Shade	OBL	Perennial	Yes	Excellent growth; herbal uses
Violet, Common Blue (*Viola papilionacea*)	Full Sun-Full Shade	FAC	Perennial	No	Stemless; spreads
Virginia Wild Rye (*Elymus virginicus*)	Part Shade-Full Shade	FACW-	Grass	Yes	Adaptable

[1]Notes:
FAC = Facultative, equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).
FACU = Facultative Upland, usually occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%).
FACW = FACW Facultative Wetland, usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.
OBL = Obligate Wetland, occurs almost always (estimated probability 99%) under natural conditions in wetlands.

Sources: Prince George's County Maryland Bioretention Manual; Virginia DCR Stormwater Design Specification No. 9: Bioretention.

Table 3.24 Woody Plants Appropriate for Bioretention Areas in the District

Plant	Light	Wetland Indicator[1]	Plant Form	Inundation Tolerance	Notes
Arrow-wood *(Viburnum dentatum)*	Full Sun-Part Shade	FAC	Shrub	Seasonal	Salt tolerant
River Birch *(Betula nigra)*	Full Sun-Part Shade	FACW	Tree	Seasonal	Attractive bark
Bayberry, Northern *(Myrica pennsylvanica)*	Full Sun-Part Shade	FAC	Shrub	Seasonal	Salt tolerant
Black Gum *(Nyssa sylvatica)*	Full Sun-Part Shade	FACW+	Tree	Seasonal	Excellent fall color
Dwarf Azalea *(Rhododendron atlanticum)*	Part Shade	FAC	Shrub	Yes	Long lived
Black-Haw *(Viburnum prunifolium)*	Part Shade-Full Shade	FACU+	Shrub	Yes	Edible Fruit
Choke Cherry *(Prunus virginiana)*	Full Sun	FACU+	Shrub	Yes	Tolerates some salt; can be maintained as hedge
Cedar, Eastern Red *(Juniperus virginiana)*	Full Sun	FACU	Tree	No	Pollution tolerant
Cotton-wood, Eastern *(Populus deltoides)*	Full Sun	FAC	Tree	Seasonal	Pollutant tolerant; salt tolerant
Silky Dogwood *(Cornus amomum)*	Full Sun-Part Shade	FACW	Shrub	Seasonal	High wildlife value
Hackberry, Common *(Celtis occidentalis)*	Full Sun-Full Shade	FACU	Tree	Seasonal	Pollution Tolerant
Hazelnut, American *(Corylus americana)*	Part Shade	FACU	Shrub	No	Forms thickets; edible nut
Holly, Winterberry *(Ilex laevigata)*	Full Sun-Part Shade	OBL	Shrub	Yes	Winter food source for birds

Plant	Light	Wetland Indicator[1]	Plant Form	Inundation Tolerance	Notes
Holly, American *(Ilex opaca)*	Full Sun-Full Shade	FACU	Shrub-Tree	Limited	Pollution Tolerant
Maple, Red *(Acer rubrum)*	Full Sun-Part Shade	FAC	Tree	Seasonal	Very adaptable; early spring flowers
Ninebark, Eastern *(Physocarpus opulifolius)*	Full Sun-Part Shade	FACW-	Shrub	Yes	Drought tolerant; attractive bark
Oak, Pin *(Quercus palustris)*	Full Sun	FACW	Tree	Yes	Pollution Tolerant
Pepperbush, Sweet *(Clethra alnifolia)*	Part Shade-Full Shade	FAC+	Shrub	Seasonal	Salt tolerant
Winterberry, Common *(Ilex verticillata)*	Full Sun-Full Shade	FACW+	Shrub	Seasonal	Winter food source for birds
Witch-Hazel, American *(Hamamelia virginiana)*	Part Shade-Full Shade	FAC-	Shrub	No	Pollution tolerant

[1]Notes:
FAC = Facultative, equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).
FACU = Facultative Upland, usually occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%).
FACW = FACW Facultative Wetland, usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.
OBL = Obligate Wetland, occurs almost always (estimated probability 99%) under natural conditions in wetlands.

Sources: Prince George's County Maryland Bioretention Manual; Virginia DCR Stormwater Design Specification No. 9: Bioretention

Planting recommendations for bioretention facilities are as follows:

- The primary objective of the planting plan is to cover as much of the surface areas of the filter bed as quickly as possible. Herbaceous or ground cover layers are as or more important than more widely spaced trees and shrubs.
- Native plant species should be specified over non-native species.
- Plants should be selected based on a specified zone of hydric tolerance and must be capable of surviving both wet and dry conditions ("Wet footed" species should be planted near the center, whereas upland species do better planted near the edge).
- Woody vegetation should not be located at points of inflow; trees should not be planted directly above underdrains but should be located closer to the perimeter.
- Shrubs and herbaceous vegetation should generally be planted in clusters and at higher densities (i.e., 10 feet on-center and 1 to 1.5 feet on-center, respectively).
- If trees are part of the planting plan, a tree density of approximately one tree per 250 square feet (i.e., 15 feet on-center) is recommended.
- Designers should also remember that planting holes for trees must be at least 3 feet deep to provide enough soil volume for the root structure of mature trees. This applies even if the remaining soil media layer is shallower than 3 feet.

- Tree species should be those that are known to survive well in the compacted soils and the polluted air and water of an urban landscape.
- If trees are used, plant shade-tolerant ground covers within the drip line.
- If the bioretention area is to be used for snow storage or is to accept snowmelt runoff, it should be planted with salt-tolerant, herbaceous perennials.

3.6.6 Bioretention Construction Sequence

Soil Erosion and Sediment Controls. The following soil erosion and sediment control guidelines must be followed during construction:

- All Bioretention areas must be fully protected by silt fence or construction fencing.
- Bioretention areas intended to infiltrate runoff must remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment and loss of design infiltration rate.
    - Where it is infeasible keep the proposed bioretention areas outside of the limits of disturbance, there are several possible outcomes for the impacted area. If excavation in the proposed bioretention area can be restricted then the remediation can be achieved with deep tilling practices. This is only possible if in-situ soils are not disturbed any deeper than 2 feet above the final design elevation of the bottom of the bioretention. In this case, when heavy equipment activity has ceased, the area is excavated to grade, and the impacted area must be tilled to a depth of 12 inches below the bottom of the bioretention.
    - Alternatively, if it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, and excavation of the area cannot be restricted, then infiltration tests will be required prior to installation of the bioretention to ensure that the design infiltration rate is still present. If tests reveal the loss of design infiltration rates then deep tilling practices may be used in an effort to restore those rates. In this case further testing must be done to establish design rates exist before the permeable pavement can be installed.
    - Finally, if it is infeasible to keep the proposed bioretention areas outside of the limits of disturbance, and excavation of the area cannot be restricted, and infiltration tests reveal design rates cannot be restored, then a resubmission of the SWMP will be required.
- Bioretention areas must be clearly marked on all construction documents and grading plans.
- Large bioretention applications may be used as small sediment traps or basins during construction. However, these must be accompanied by notes and graphic details on the soil erosion and sediment control plan specifying that (1) the maximum excavation depth of the trap or basin at the construction stage must be at least 1 foot higher than the post-construction (final) invert (bottom of the facility), and (2) the facility must contain an underdrain. The plan must also show the proper procedures for converting the temporary sediment control practice to a permanent bioretention BMP, including dewatering, cleanout, and stabilization.

Bioretention Installation. The following is a typical construction sequence to properly install a bioretention basin. The construction sequence for micro-bioretention is more simplified. These steps may be modified to reflect different bioretention applications or expected site conditions:

Step 1: **Stabilize Drainage Area.** Construction of the bioretention area may only begin after the entire contributing drainage area has been stabilized with vegetation. It may be necessary to block certain curb or other inlets while the bioretention area is being constructed. The proposed site should be checked for existing utilities prior to any excavation.

Step 2: **Preconstruction Meeting.** The designer, the installer, and DDOE inspector must 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 inspector. Material certifications for aggregate, soil media and any geotextiles must be submitted for approval to the inspector at the preconstruction meeting.

Step 3: **Install Soil Erosion and Sediment Control Measures to Protect the Bioretention.** Temporary soil erosion and sediment controls (e.g., diversion dikes, reinforced silt fences) are needed during construction of the bioretention area to divert stormwater away from the bioretention area until it is completed. Special protection measures, such as erosion control fabrics, may be needed to protect vulnerable side slopes from erosion during the construction process.

Step 4: **Install Pretreatment Cells.** Any pretreatment cells should be excavated first and then sealed to trap sediment.

Step 5: **Avoid Impact of Heavy Installation Equipment.** Excavators or backhoes should work from the sides to excavate the bioretention area to its appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the bioretention area. Contractors should use a cell construction approach in larger bioretention basins, whereby the basin is split into 500- to 1,000-square foot temporary cells with a 10- to15-foot earth bridge in between, so that cells can be excavated from the side.

Step 6: **Promote Infiltration Rate.** It may be necessary to rip the bottom soils to a depth of 6 to 12 inches to promote greater infiltration.

Step 7: **Order of Materials.** If using a geotextile fabric, place the fabric on the sides of the bioretention area with a 6-inch overlap on the sides. If a stone storage layer will be used, place the appropriate depth of No. 57 stone (clean double washed) on the bottom, install the perforated underdrain pipe, pack No. 57 stone to 3 inches above the underdrain pipe, and add the choking layer or appropriate geotextile layer as a filter between the underdrain and the soil media layer. If no stone storage layer is used, start with 6 inches of No. 57 stone on the bottom and proceed with the layering as described above.

Step 8: **Layered Installation of Media**. Apply the media in 12-inch lifts until the desired top elevation of the bioretention area is achieved. Wait a few days to check for settlement and add additional media, as needed, to achieve the design elevation.

Note: The batch receipt confirming the source of the soil media must be submitted to the DDOE inspector.

Step 9: **Prepare Filter Media for Plants.** Prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly. Install any temporary irrigation.

Step 10: **Planting.** Install the plant materials as shown in the landscaping plan, and water them as needed.

Step 11: **Secure Surface Area.** Place the surface cover (i.e., mulch, river stone, or turf) in both cells, depending on the design. If coir or jute matting will be used in lieu of mulch, the matting will need to be installed prior to planting (Step 10), and holes or slits will have to be cut in the matting to install the plants.

Step 12: **Inflows.** If curb cuts or inlets are blocked during bioretention installation, unblock these after the drainage area and side slopes have good vegetative cover. It is recommended that unblocking curb cuts and inlets take place after two to three storm events if the drainage area includes newly installed asphalt, since new asphalt tends to produce a lot of fines and grit during the first several storms.

Step 13: **Final Inspection.** Conduct the final construction inspection using a qualified professional, providing DDOE with an as-built, then log the GPS coordinates for each bioretention facility, and submit them for entry into the maintenance tracking database.

Construction Supervision. Supervision during construction is recommended to ensure that the bioretention area is built in accordance with the approved design and this specification. Qualified individuals should use detailed inspection checklists that include sign-offs at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intentions.

DDOE's construction phase inspection checklist can be found in Appendix K.

3.6.7 Bioretention Maintenance Criteria

When bioretention practices are installed, it is the owner's responsibility to ensure they, or those managing the practice, (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a maintenance covenant or agreement, as described below.

Maintenance of bioretention areas should be integrated into routine landscape maintenance tasks. If landscaping contractors will be expected to perform maintenance, their contracts should contain specifics on unique bioretention landscaping needs, such as maintaining elevation differences needed for ponding, proper mulching, sediment and trash removal, and limited use of fertilizers and pesticides.

Maintenance tasks and frequency will vary depending on the size and location of the bioretention, the landscaping template chosen, and the type of surface cover in the practice. A generalized summary of common maintenance tasks and their frequency is provided in Table 3.25.

Table 3.25 Typical Maintenance Tasks for Bioretention Practices

Frequency	Maintenance Tasks
Upon establishment	▪ For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization. ▪ 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. ▪ One-time, spot fertilization may be needed for initial plantings. ▪ Watering is needed once a week during the first 2 months, and then as needed during first growing season (April-October), depending on rainfall. ▪ Remove and replace dead plants. Up to 10% of the plant stock may die off in the first year, so construction contracts should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.
At least 4 times per year	▪ Mow grass filter strips and bioretention with turf cover ▪ Check curb cuts and inlets for accumulated grit, leaves, and debris that may block inflow
Twice during growing season	▪ Spot weed, remove trash, and rake the mulch
Annually	▪ Conduct a maintenance inspection ▪ Supplement mulch in devoid areas to maintain a 3 inch layer ▪ Prune trees and shrubs ▪ Remove sediment in pretreatment cells and inflow points
Once every 2–3 years	▪ Remove sediment in pretreatment cells and inflow points ▪ Remove and replace the mulch layer
As needed	▪ Add reinforcement planting to maintain desired vegetation density ▪ Remove invasive plants using recommended control methods ▪ Remove any dead or diseased plants ▪ Stabilize the contributing drainage area to prevent erosion

Standing water is the most common problem outside of routine maintenance. If water remains on the surface for more than 72 hours after a storm, adjustments to the grading may be needed or underdrain repairs may be needed. The surface of the filter bed should also be checked for accumulated sediment or a fine crust that builds up after the first several storm events. There are several methods that can be used to rehabilitate the filter. These are listed below, starting with the simplest approach and ranging to more involved procedures (i.e., if the simpler actions do not solve the problem):

- Open the underdrain observation well or cleanout and pour in water to verify that the underdrains are functioning and not clogged or otherwise in need of repair. The purpose of this check is to see if there is standing water all the way down through the soil. If there is standing water on top, but not in the underdrain, then there is a clogged soil layer. If the underdrain and stand pipe indicates standing water, then the underdrain must be clogged and will need to be cleaned out.
- Remove accumulated sediment and till 2 to 3 inches of sand into the upper 6 to 12 inches of soil.

- Install sand wicks from 3 inches below the surface to the underdrain layer. This reduces the average concentration of fines in the media bed and promotes quicker drawdown times. Sand wicks can be installed by excavating or auguring (i.e., using a tree auger or similar tool) down to the top of the underdrain layer to create vertical columns which are then filled with a clean open-graded coarse sand material (e.g., 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.

Maintenance Inspections. It is recommended that a qualified professional conduct a spring maintenance inspection and cleanup at each bioretention area. Maintenance inspections should include information about the inlets, the actual bioretention facility (sediment buildup, outlet conditions, etc.), and the state of vegetation (water stressed, dead, etc.) and are intended to highlight any issues that need or may need attention to maintain stormwater management functionality.

DDOE's maintenance inspection checklists for bioretention areas and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.6.8 Bioretention Stormwater Compliance Calculations

Bioretention performance varies depending on the design configuration of the system.

Enhanced Designs. These designs are bioretention applications with no underdrain or at least 24 inches of filter media and an infiltration sump. Enhanced designs receive 100 percent retention value for the amount of storage volume (Sv) provided by the practice (Table 3.26), and, therefore, are not considered an accepted total suspended solids (TSS) treatment practice.

Table 3.26 Enhanced Bioretention Retention Value and Pollutant Removal

Retention Value	= *Sv*
Accepted TSS Treatment Practice	N/A

Standard Designs. These designs are bioretention applications with an underdrain and less than 24 inches of filter media. Standard designs receive 60 percent retention value and are an accepted TSS removal practice for the amount of storage volume (Sv) provided by the practice (Table 3.27).

Table 3.27 Standard Bioretention Design Retention Value and Pollutant Removal

Retention Value	$= 0.6 \times Sv$
Accepted TSS Treatment Practice	Yes

The practice must be sized using the guidance detailed in Section 3.6.4.

Note: Additional retention value can be achieved if trees are utilized as part of a bioretention area (see Section 3.2.3 Green Roof Pretreatment Criteria).

Bioretention also contributes to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the Sv or Rv from the total runoff volume for the 2-year, 15-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a Reduced Natural Resource Conservation Service (NRCS) Curve Number for the site or drainage area. The Reduced Curve Number can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

3.6.9 References

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3.7 Filtering Systems

Definition. Practices that capture and temporarily store the design storm volume and pass it through a filter bed of sand media. Filtered runoff may be collected and returned to the conveyance system or allowed to partially infiltrate into the soil. Design variants include:

F-1 Non-structural sand filter

F-2 Surface sand filter

F-3 Three-chamber underground sand filter

F-4 Perimeter sand filter

Stormwater filters are a useful practice to treat stormwater runoff from small, highly impervious sites. Stormwater filters capture, temporarily store, and treat stormwater runoff by passing it through an engineered filter media, collecting the filtered water in an underdrain, and then returning it back to the storm drainage system. The filter consists of two chambers: the first is devoted to settling and the second serves as a filter bed consisting of a sand filter media.

Stormwater filters are a versatile option because they consume very little surface land and have few site restrictions. They provide moderate pollutant removal performance at small sites where space is limited. However, filters have no retention capability, so designers should consider using up-gradient retention practices, which have the effect of decreasing the design storm volume and size of the filtering practices. Filtering practices are also suitable to provide special treatment at designated stormwater hotspots. A list of potential stormwater hotspots operations can be found in Appendix P.

Filtering systems are typically not to be designed to provide stormwater detention (Qp_2, Qp_{15}), but they may be in some circumstances. Filtering practices are generally combined with separate facilities to provide this type of control. However, the three-chamber underground sand filter can be modified by expanding the first or settling chamber, or adding an extra chamber between the filter chamber and the clear well chamber to handle the detention volume, which is subsequently discharged at a predetermined rate through an orifice and weir combination.

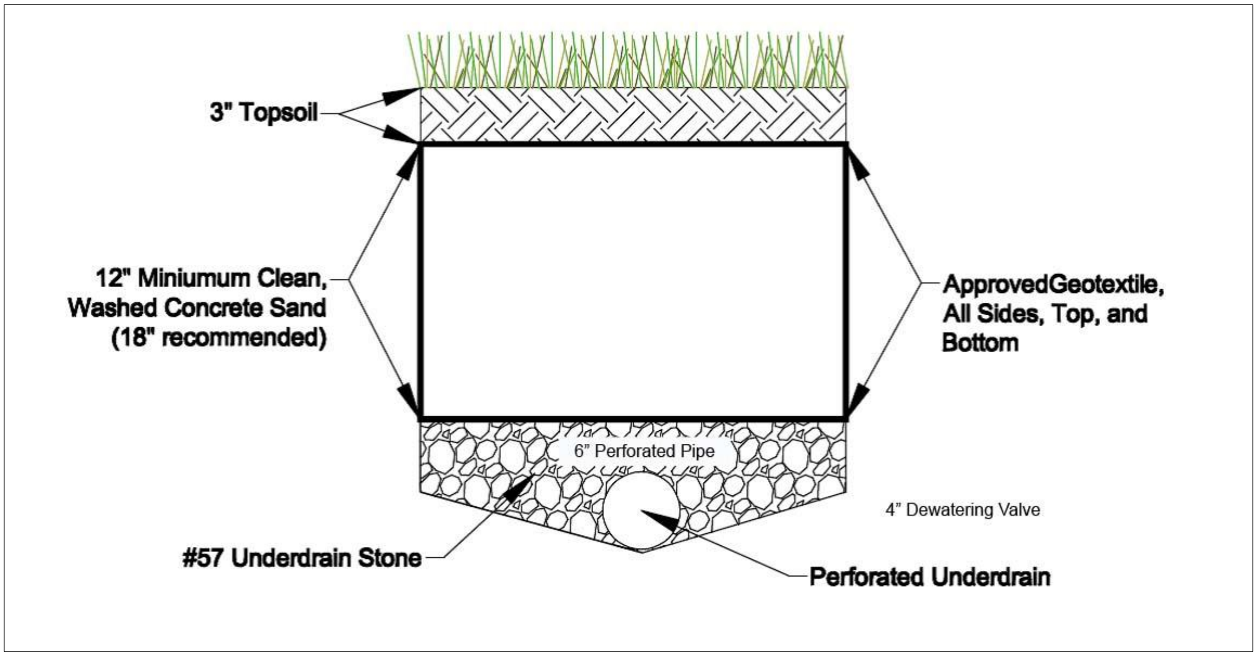

Figure 3.21 Typical schematic for a surface sand filter (F-2).
Note: Material specifications are indicated in Table 3.28.

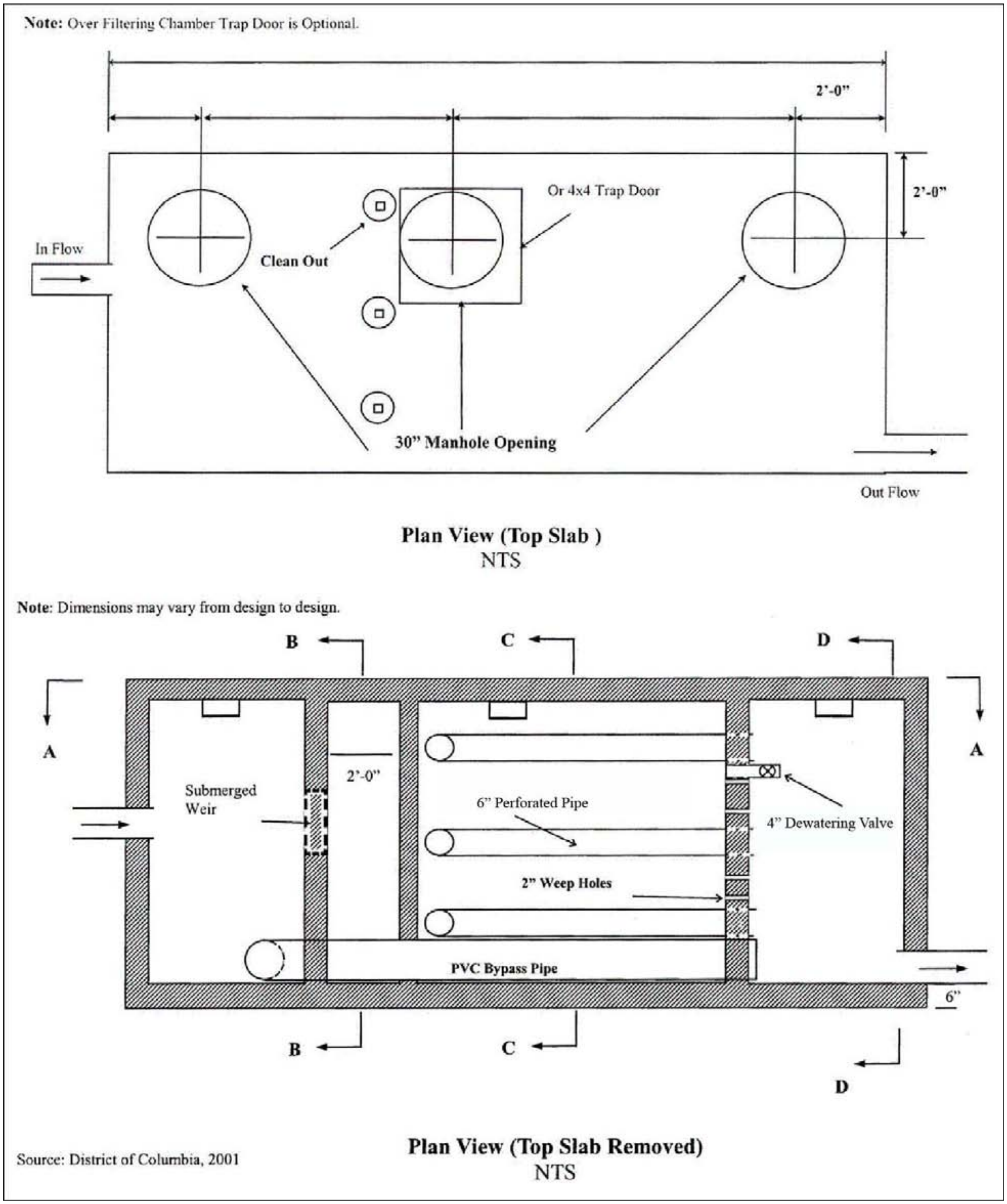

Figure 3.22 Part A – Example of a three-chamber underground sand filter (F-3) for separate sewer areas. Note: Material specifications are indicated in Table 3.28.

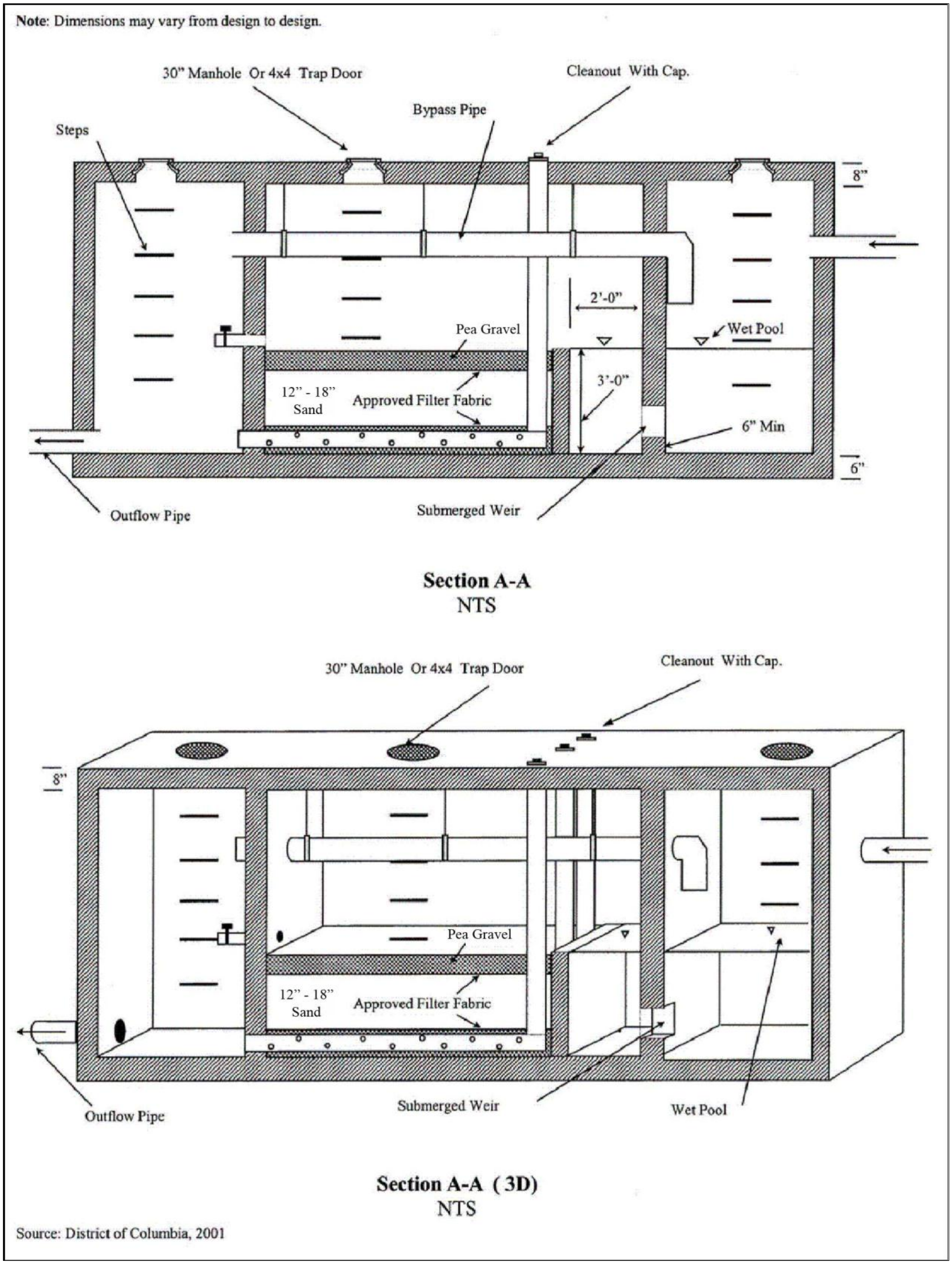

Figure 3.23 Part B – Example of a three-chamber underground sand filter (F-3) for separate sewer areas. Note: Material specifications are indicated in Table 3.28.

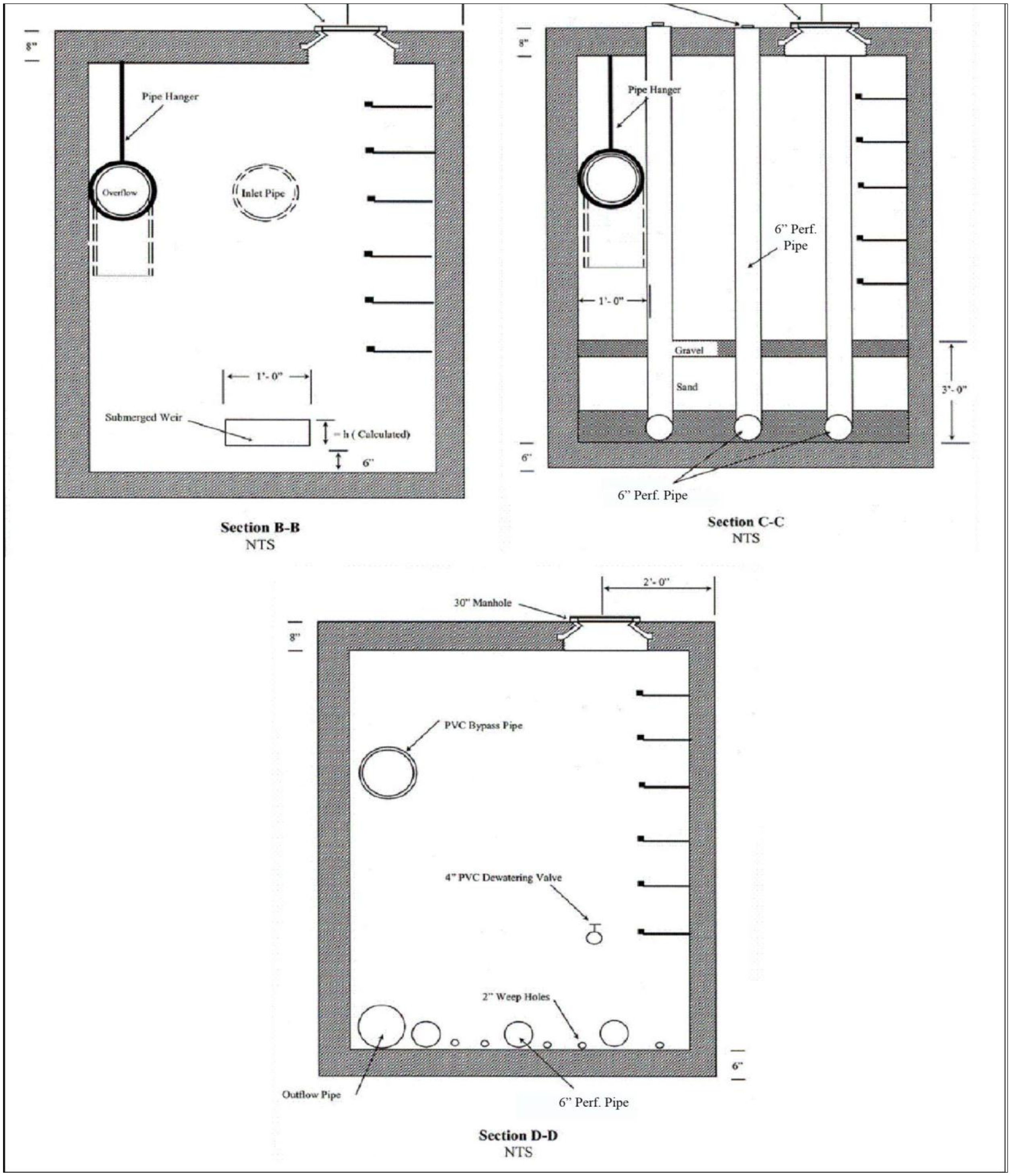

Figure 3.24 Part C – Example of a three-chamber underground sand filter (F-3) for separate sewer areas. Note: Material specifications are indicated in Table 3.28.

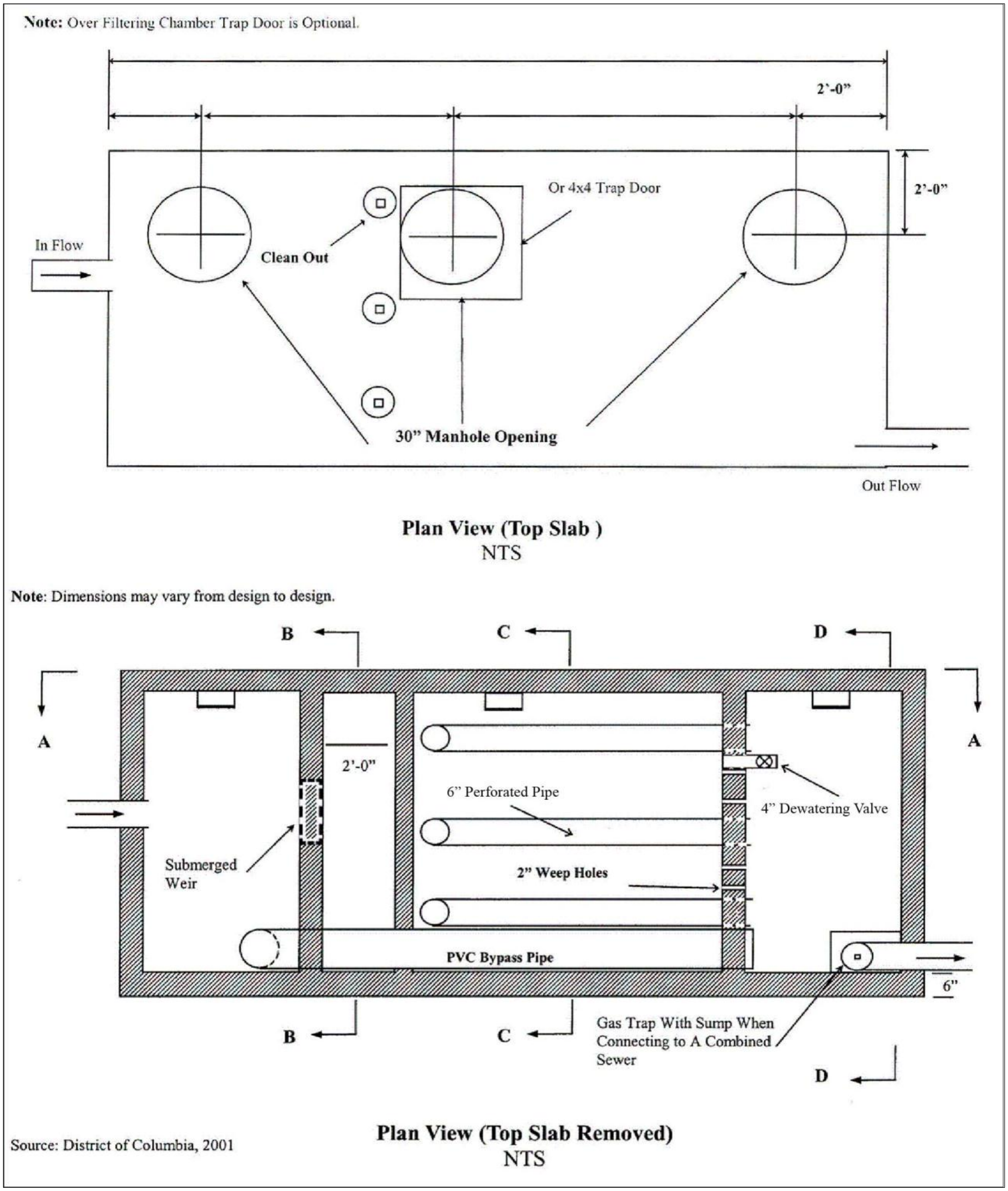

Figure 3.25 Part A – Example of a three-chamber underground sand filter (F-3) for combined sewer areas. Note: Material specifications are indicated in Table 3.28.

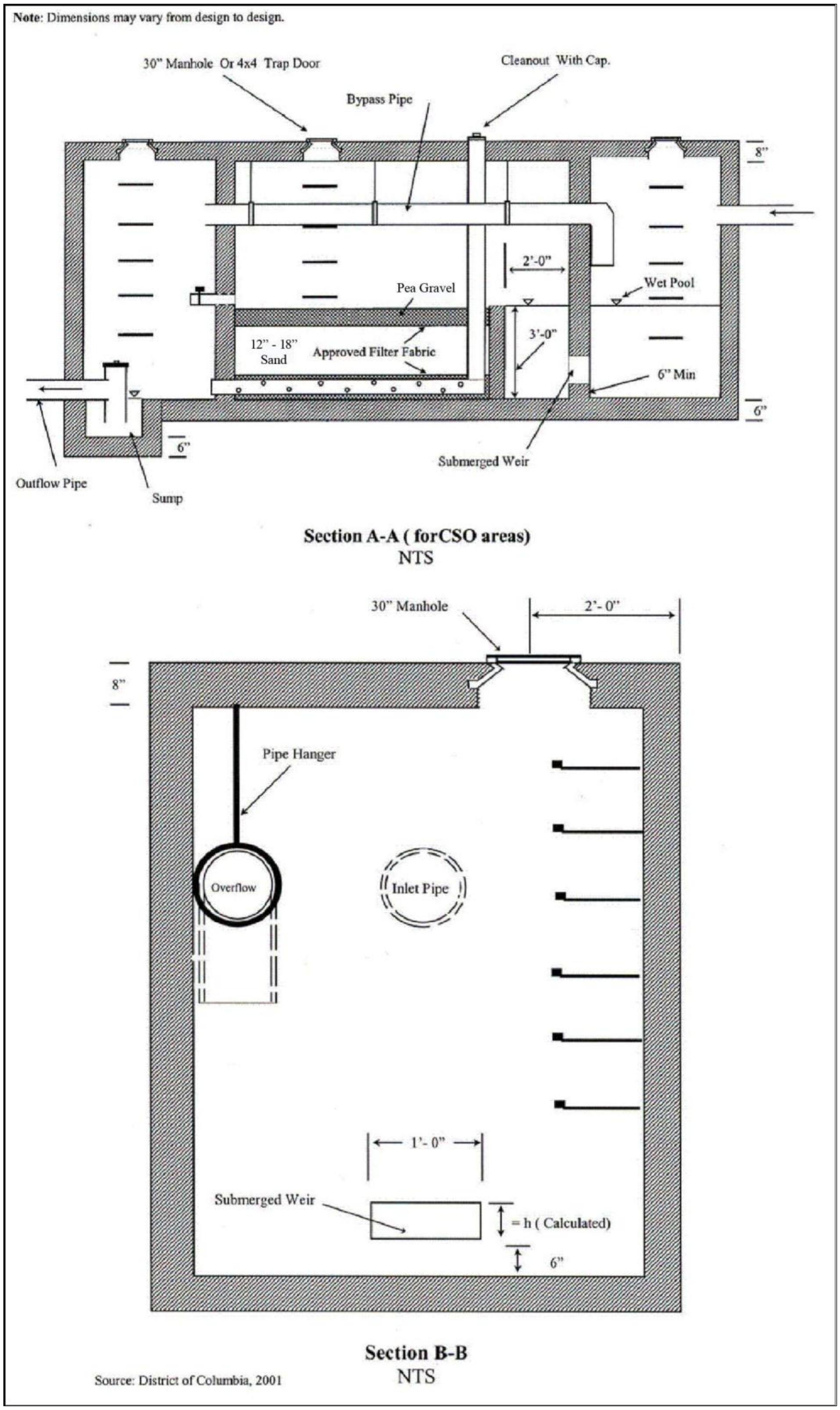

Figure 3.26 Part B – Example of a three-chamber underground sand filter (F-3) for combined sewer areas. Note: Material specifications are indicated in Table 3.28.

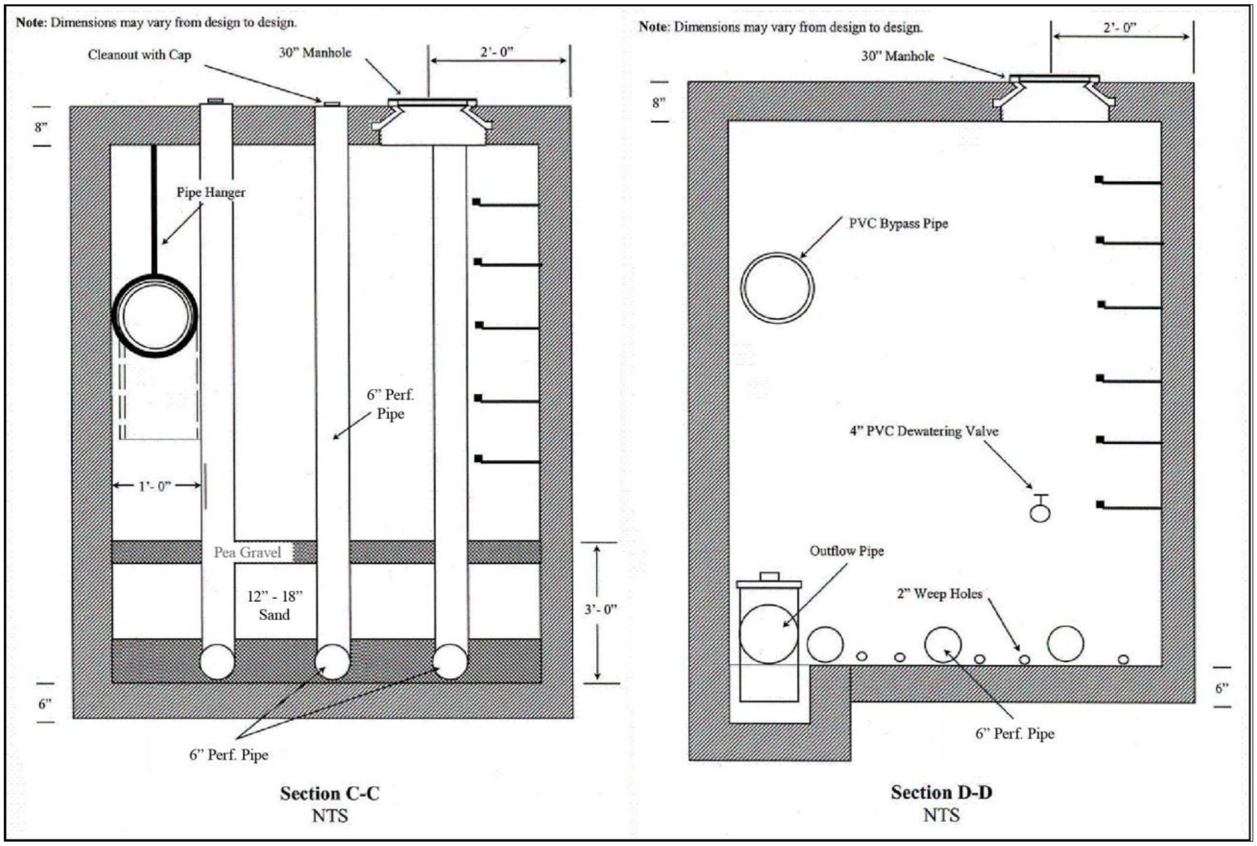

Figure 3.27 Part C – Example of a three-chamber underground sand filter (F-3) for combined sewer areas. Note: Material specifications are indicated in Table 3.28.

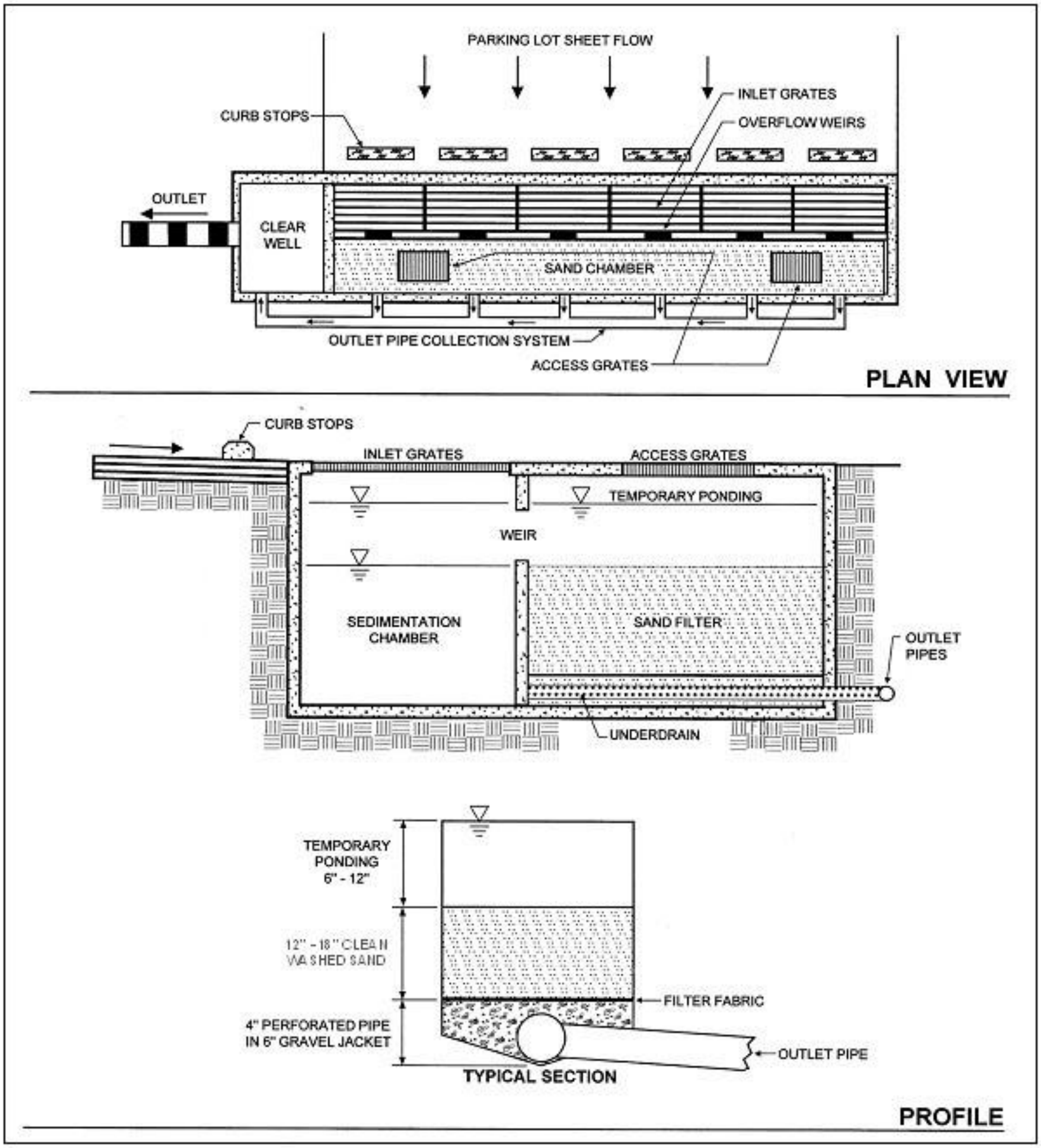

Figure 3.28 Example of a perimeter sand filter (F-4).
Note: Material specifications are indicated in Table 3.28.

3.7.1 Filtering Feasibility Criteria

Stormwater filters can be applied to most types of urban land. They are not always cost-effective, given their high unit cost and small area served, but there are situations where they may clearly be the best option for stormwater treatment (e.g., hotspot runoff treatment, small parking lots, ultra-urban areas, etc.). The following criteria apply to filtering practices:

Available Hydraulic Head. The principal design constraint for stormwater filters is available hydraulic head, which is defined as the vertical distance between the top elevation of the filter and the bottom elevation of the existing storm drain system that receives its discharge. The head required for stormwater filters ranges from 2 to 10 feet, depending on the design variant. It is difficult to employ filters in extremely flat terrain, since they require gravity flow through the filter. The only exception is the perimeter sand filter, which can be applied at sites with as little as 2 feet of head.

Depth to Water Table and Bedrock. The designer must assure a standard separation distance of at least 2 feet between the seasonally high groundwater table and/or bedrock layer and the bottom invert of the filtering practice.

Contributing Drainage Area. Filters are best applied on small sites where the contributing drainage (CDA) area is as close to 100 percent impervious as possible in order to reduce the risk that eroded sediment will clog the filter. If the CDA is pervious, then the vegetation must be dense and stable. Turf is acceptable (see Section 3.7.5 Filtering Landscaping Criteria). A maximum CDA of 5 acres is recommended for surface sand filters, and a maximum CDA of 2 acres is recommended for perimeter or underground filters. Filters have been used on larger drainage areas in the past, but greater clogging problems have typically resulted. The one-chamber sand filter is only applicable for impervious area less than 10,000 ft^2 (1/4 acre).

Space Required. The amount of space required for a filter practice depends on the design variant selected. Surface sand filters typically consume about 2 to 3 percent of the CDA, while perimeter sand filters typically consume less than 1 percent. Underground stormwater filters generally consume no surface area except their manholes.

Land Use. As noted above, filters are particularly well suited to treat runoff from stormwater hotspots and smaller parking lots. Other applications include redevelopment of commercial sites or when existing parking lots are renovated or expanded. Filters can work on most commercial, industrial, institutional, or municipal sites and can be located underground if surface area is not available.

Site Topography. Filters shall not be located on slopes greater than 6 percent.

Utilities. All utilities shall have a minimum 5-foot, horizontal clearance from the filtering practice.

Facility Access. All filtering systems shall be located in areas where they are accessible for inspection and for maintenance (by vacuum trucks).

Soils. Soil conditions do not constrain the use of filters. At least one soil boring must be taken at a low point within the footprint of the proposed filtering practice to establish the water table and bedrock elevations and evaluate soil suitability. A geotechnical investigation is required for all underground stormwater best management practices (BMPs), including underground filtering systems. Geotechnical testing requirements are outlined in Appendix O.

3.7.2 Filtering Conveyance Criteria

Most filtering practices are designed as off-line systems so that all flows enter the filter storage chamber until it reaches capacity, at which point larger flows are then diverted or bypassed around the filter to an outlet chamber and are not treated. Runoff from larger storm events must be bypassed using an overflow structure or a flow splitter. Claytor and Schueler (1996) and ARC (2001) provide design guidance for flow splitters for filtering practices.

Some underground filters will be designed and constructed as on-line BMPs. In these cases, designers must indicate how the device will safely pass larger storm events (e.g., the 15-year event) to a stabilized water course without resuspending or flushing previously trapped material.

All stormwater filters must be designed to drain or dewater within 72 hours after a storm event to reduce the potential for nuisance conditions.

3.7.3 Filtering Pretreatment Criteria

Adequate pretreatment is needed to prevent premature filter clogging and ensure filter longevity. Dry or wet pretreatment shall be provided prior to filter media. Pretreatment devices are subject to the following criteria:

- Sedimentation chambers are typically used for pretreatment to capture coarse sediment particles before they reach the filter bed.
- Sedimentation chambers may be wet or dry but must be sized to accommodate at least 25 percent of the total design storm volume (inclusive).
- Sediment chambers should be designed as level spreaders such that inflows to the filter bed have near zero velocity and spread runoff evenly across the bed.
- Non-structural and surface sand filters may use alternative pretreatment measures, such as a grass filter strip, forebay, gravel diaphragm, check dam, level spreader, or a combination of these. The grass filter strip must be a minimum length of 15 feet and have a slope of 3 percent or less. The check dam may be wooden or concrete and must be installed so that it extends only 2 inches above the filter strip and has lateral slots to allow runoff to be evenly distributed across the filter surface. Alternative pretreatment measures must contain a non-erosive flow path that distributes the flow evenly over the filter surface. If a forebay is used, it must be designed to accommodate at least 25 percent of the total design storm volume (inclusive).

3.7.4 Filtering Design Criteria

Detention time. All filter systems must be designed to drain the design storm volume from the filter chamber within 72 hours after each rainfall event.

Structural Requirements. If a filter will be located underground or experience traffic loads, a licensed structural engineer must certify the structural integrity of the design.

Geometry. Filters are gravity flow systems that normally require 2 to 5 feet of driving head to push the water through the filter media through the entire maintenance cycle; therefore, sufficient vertical clearance between the inverts of the inflow and outflow pipes is required.

Type of Filter Media. The normal filter media consists of clean, washed AASHTO M-6/ASTM C-33 medium aggregate concrete sand with individual grains between 0.02 and 0.04 inches in diameter.

Depth of Filter Media. The depth of the filter media plays a role in how quickly stormwater moves through the filter bed and how well it removes pollutants. The recommended filter bed depth is 18 inches. An absolute minimum filter bed depth of 12 inches above underdrains is required; although, designers should note that specifying the minimum depth of 12 inches will incur a more intensive maintenance schedule and possibly result in more costly maintenance.

Underdrain and Liner. Stormwater filters are normally designed with an impermeable liner and underdrain system that meet the criteria provided in Table 3.28 below.

Underdrain Stone. The underdrain should be covered by a minimum 6-inch gravel layer consisting of clean, double washed No. 57 stone.

Type of Filter. There are several design variations of the basic filter that enable designers to use filters at challenging sites or to improve pollutant removal rates. The choice of which filter design to apply depends on available space, hydraulic head, and the level of pollutant removal desired. In ultra-urban situations where surface space is at a premium, underground sand filters are often the only design that can be used. Surface and perimeter filters are often a more economical choice when adequate surface area is available. The most common design variants include the following:

- **Non-Structural Sand Filter (F-1).** The non-structural sand filter is applied to sites less than 2 acres in size and is very similar to a bioretention practice (see Section 3.6 Bioretention), with the following exceptions:
  - The bottom is lined with an impermeable liner and always has an underdrain.
  - The surface cover is sand, turf, or pea gravel.
  - The filter media is 100 percent sand.
  - The filter surface is not planted with trees, shrubs, or herbaceous materials.
  - The filter has two cells, with a dry or wet sedimentation chamber preceding the sand filter bed.

The non-structural sand filter is the least expensive filter option for treating hotspot runoff. The use of bioretention areas is generally preferred at most other sites.

- **Surface Sand Filter (F-2).** The surface sand filter is designed with both the filter bed and sediment chamber located at ground level. The most common filter media is sand; however, a peat/sand mixture may be used to increase the removal efficiency of the system. In most cases, the filter chambers are created using precast or cast-in-place concrete. Surface sand filters are normally designed to be off-line facilities, so that only the desired design volume is directed to the filter for treatment. However, in some cases they can be installed on the bottom of a Dry Extended Detention (ED) Pond (see Section 3.9 Open Channel Systems).
- **Underground Sand Filter.** The underground sand filter is modified to install the filtering components underground and is often designed with an internal flow splitter or overflow device that bypasses runoff from larger stormwater events around the filter. Underground sand filters are expensive to construct, but they consume very little space and are well suited to ultra-urban areas.
- **Three-Chamber Underground Sand Filter (F-3).** The three-chamber underground sand filter is a gravity flow system. The facility may be precast or cast-in-place. The first chamber acts as a pretreatment facility removing any floating organic material such as oil, grease, and tree leaves. It should have a submerged orifice leading to a second chamber, and it should be designed to minimize the energy of incoming stormwater before the flow enters the second chamber (i.e., filtering or processing chamber).

  The second chamber is the filtering or processing chamber. It should contain the filter material consisting of gravel and sand and should be situated behind a weir. Along the bottom of the structure should be a subsurface drainage system consisting of a parallel perforated PVC pipe system in a stone bed. A dewatering valve should be installed at the top of the filter layer for safety release in cases of emergency. A bypass pipe crossing the second chamber to carry overflow from the first chamber to the third chamber is required.

  The third chamber is the discharge chamber. It should also receive the overflow from the first chamber through the bypass pipe when the storage volume is exceeded.

  Water enters the first chamber of the system by gravity or by pumping. This chamber removes most of the heavy solid particles, floatable trash, leaves, and hydrocarbons. Then the water flows to the second chamber and enters the filter layer by overtopping a weir. The filtered stormwater is then picked up by the subsurface drainage system that empties it into the third chamber.

  Whenever there is insufficient hydraulic head for a three-chamber underground sand filter, a well pump may be used to discharge the effluent from the third chamber into the receiving storm or combined sewer. For three-chamber sand filters in combined-sewer areas, a water trap shall be provided in the third chamber to prevent the back flow of odorous gas.
- **Perimeter Sand Filter (F-74).** The perimeter sand filter also includes the basic design elements of a sediment chamber and a filter bed. The perimeter sand filter typically consists of two parallel trenches connected by a series of overflow weir notches at the top of the partitioning wall, which allows water to enter the second trench as sheet flow. The first trench is a pretreatment chamber removing heavy sediment particles and debris. The second trench consists of the sand filter layer. A subsurface drainage pipe must be installed at the

bottom of the second chamber to facilitate the filtering process and convey filter water into a receiving system.

In this design, flow enters the system through grates, usually at the edge of a parking lot. The perimeter sand filter is usually designed as an on-line practice (i.e., all flows enter the system), but larger events bypass treatment by entering an overflow chamber. One major advantage of the perimeter sand filter design is that it requires little hydraulic head and is therefore a good option for sites with low topographic relief.

Surface Cover. The surface cover for non-structural and surface sand filters should consist of a 3-inch layer of topsoil on top of the sand layer. The surface may also have pea gravel inlets in the topsoil layer to promote filtration. The pea gravel may be located where sheet flow enters the filter, around the margins of the filter bed, or at locations in the middle of the filter bed.

Underground sand filters should have a pea gravel layer on top of the sand layer. The pea gravel helps to prevent bio-fouling or blinding of the sand surface.

Maintenance Reduction Features. The following maintenance issues should be addressed during filter design to reduce future maintenance problems:

- **Observation Wells and Cleanouts.** Non-structural and surface sand filters must include an observation well consisting of a 6-inch diameter non-perforated PVC pipe fitted with a lockable cap. It should be installed flush with the ground surface to facilitate periodic inspection and maintenance. In most cases, a cleanout pipe will be tied into the end of all underdrain pipe runs. The portion of the cleanout pipe/observation well in the underdrain layer should be perforated. At least one cleanout pipe must be provided for every 2000 square feet of filter surface area.
- **Access.** Good maintenance access is needed to allow crews to perform regular inspections and maintenance activities. "Sufficient access" is operationally defined as the ability to get a vacuum truck or similar equipment close enough to the sedimentation chamber and filter to enable cleanouts. Direct maintenance access shall be provided to the pretreatment area and the filter bed. For underground structures, sufficient headroom for maintenance should be provided. A minimum head space of 5 feet above the filter is recommended for maintenance of the structure. However, if 5 feet headroom is not available, manhole access must be installed.
- **Manhole Access (for underground filters).** Access to the headbox and clearwell of Underground Filters must be provided by manholes at least 30 inches in diameter, along with steps to the areas where maintenance will occur.
- **Visibility.** Stormwater filters should be clearly visible at the site so inspectors and maintenance crews can easily find them. Adequate signs or markings must be provided at manhole access points for Underground Filters.
- **Confined Space Issues.** Underground filters are often classified as a confined space. Consequently, special OSHA rules apply, and training may be needed to protect the workers that access them. These procedures often involve training about confined space entry, venting, and the use of gas probes.

Filter Material Specifications. The basic material specifications for filtering practices that utilize sand as a filter media are outlined in Table 3.28.

Table 3.28 Filtering Practice Material Specifications

Material	Specification
Surface Cover	Non-structural and surface sand filters: 3-inch layer of topsoil on top of the sand layer. The surface may also have pea gravel inlets in the topsoil layer to promote filtration. Underground sand filters: Clean, double washed No. 57 stone on top of the sand layer.
Sand	Clean AASHTO M-6/ASTM C-33 medium aggregate concrete sand with a particle size range of 0.02 to 0.04 inch in diameter.
Geotextile/Filter Fabric	An appropriate geotextile fabric that meets AASHTO M-288 Class 2, latest edition, requirements
Underdrain/Perforated Pipe	4- or 6-inch perforated schedule 40 PVC pipe, with 3/8-inch perforations at 6 inches on center.
Underdrain Stone	Use #57 stone or the ASTM equivalent (1 inch maximum).
Impermeable Liner	Where appropriate, use a thirty mil (minimum) PVC Geomembrane

Filter Sizing. Filtering devices are sized to accommodate a specified design storm volume (typically Stormwater Retention Volume (SWRv)). The volume to be treated by the device is a function of the storage depth above the filter and the surface area of the filter. The storage volume is the volume of ponding above the filter. For a given design volume, Equation 3.10 below is used to determine the required filter surface area.

Equation 3.6 Minimum Filter Surface Area for Filtering Practices

$$SA_{filter} = \frac{DesignVolume \times d_f}{k \times (h_{avg} + d_f) \times t_f}$$

where:

SA_{filter}	=	area of the filter surface (ft^2)
$DesignVolume$	=	design storm volume, typically the SWRv (ft^2)
d_f	=	filter media depth (thickness) (ft), with a minimum of 1 ft
k	=	coefficient of permeability (ft/day) (3.5 ft/day for partially clogged sand)
h_f	=	height of water above the filter bed (ft), with a maximum of 5 ft
h_{avg}	=	average height of water above the filter bed (ft), one half of the filter height (h_f)
t_f	=	allowable drawdown time (1.67 days)

The coefficient of permeability (ft/day) is intended to reflect the worst case situation (i.e., the condition of the sand media at the point in its operational life where it is in need of replacement or maintenance). Filtering practices are therefore sized to function within the desired constraints at the end of the media's operational life cycle.

The entire filter treatment system, including pretreatment, shall temporarily hold at least 50 percent of the design storm volume prior to filtration (see Equation 3.7). This reduced volume takes into account the varying filtration rate of the water through the media, as a function of a gradually declining hydraulic head.

Equation 3.7 Required Ponding Volume for Filtering Practices

$$V_{ponding} = 0.50 \times DesignVolume$$

where:

$V_{ponding}$	=	storage volume required prior to filtration (ft^3)
$DesignVolume$	=	design storm volume, typically the SWRv (ft^2)

The total storage volume for the practice (Sv) can be determined using Equation 3.8 below.

Equation 3.8 Storage Volume for Filtering Practices

$$Sv = 2.0 \times V_{ponding}$$

where:

Sv	=	total storage volume for the practice (ft^3)
$V_{ponding}$	=	storage volume required prior to filtration (ft^3)

3.7.5 Filtering Landscaping Criteria

A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility. Filtering practices should be incorporated into site landscaping to increase their aesthetics and public appeal.

Surface filters (e.g., surface and non-structural sand filters) can have a grass cover to aid in pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought.

3.7.6 Filter Construction Sequence

Soil Erosion and Sediment Control. No runoff shall be allowed to enter the filter system prior to completion of all construction activities, including revegetation and final site stabilization. Construction runoff shall be treated in separate sedimentation basins and routed to bypass the filter system. Should construction runoff enter the filter system prior to final site stabilization, all contaminated materials must be removed and replaced with new clean filter materials before a regulatory inspector approves its completion. The approved soil erosion and sediment control plan (SESCP) shall include specific measures to provide for the protection of the filter system before the final stabilization of the site.

Filter Installation. The following is the typical construction sequence to properly install a structural sand filter. This sequence can be modified to reflect different filter designs, site conditions, and the size, complexity, and configuration of the proposed filtering application.

Step 1: **Stabilize Drainage Area.** Filtering practices should only be constructed after the contributing drainage area to the facility is completely stabilized, so sediment from the CDA does not flow into and clog the filter. If the proposed filtering area is used as a sediment trap or basin during the construction phase, the construction notes should clearly specify that, after site construction is complete, the sediment control facility will be dewatered, dredged, and re-graded to design dimensions for the post-construction filter.

Step 2: **Install Soil Erosion and Sediment Control Measures for the Filtering Practice.** Stormwater should be diverted around filtering practices as they are being constructed. This is usually not difficult to accomplish for off-line filtering practices. It is extremely important to keep runoff and eroded sediment away from the filter throughout the construction process. Silt fence or other sediment controls should be installed around the perimeter of the filter, and erosion control fabric may be needed during construction on exposed side-slopes with gradients exceeding 4H:1V. Exposed soils in the vicinity of the filtering practice should be rapidly stabilized by hydro-seed, sod, mulch, or other method.

Step 3: **Assemble Construction Materials on Site.** Inspect construction materials to insure they conform to design specifications and prepare any staging areas.

Step 4: **Clear and Strip.** Bring the project area to the desired subgrade.

Step 5: **Excavate and Grade.** Survey to achieve the appropriate elevation and designed contours for the bottom and side slopes of the filtering practice.

Step 6: **Install Filter Structure**. Install filter structure in design location and check all design elevations (i.e., concrete vaults for surface, underground, and perimeter sand filters). Upon completion of the filter structure shell, inlets and outlets must be temporarily plugged and the structure filled with water to the brim to demonstrate water tightness. Maximum allowable leakage is 5 percent of the water volume in a 24-hour period. See Appendix K for the Stormwater Facility Leak Test form. If the structure fails the test, repairs must be performed to make the structure watertight before any sand is placed into it.

Step 7: **Install Base Material Components.** Install the gravel, underdrains, and choker layers of the filter.

Step 8: **Install Top Sand Component.** Spread sand across filter bed in 1-foot lifts up to the design elevation. Backhoes or other equipment can deliver the sand from outside the filter structure. Sand should be manually raked. Clean water is then added until the sedimentation chamber and filter bed are completely full. The facility is then allowed to drain, hydraulically compacting the sand layers. After 48 hours of drying, refill the structure to the final top elevation of the filter bed.

Step 9: **Install Surface Layer (Surface Sand Filters only).** Add a 3-inch topsoil layer and pea gravel inlets and immediately seed with the permanent grass species. The grass should be watered, and the facility should not be switched on-line until a vigorous grass cover has become established.

Step 10: **Stabilize Surrounding Areas.** Stabilize exposed soils on the perimeter of the structure with temporary seed mixtures appropriate for a buffer. All areas above the normal pool should be permanently stabilized by hydroseed, sod, or seeding and mulch.

Step 11: **Final Inspection**. Conduct the final construction inspection. Multiple construction inspections by a qualified professional are critical to ensure that stormwater filters are properly constructed. Inspections are recommended during the following stages of construction:

- Initial site preparation, including installation of soil erosion and sediment control measures;
- Excavation/grading to design dimensions and elevations;
- Installation of the filter structure, including the water tightness test;
- Installation of the underdrain and filter bed;
- Check that turf cover is vigorous enough to switch the facility on-line; and
- Final inspection after a rainfall event to ensure that it drains properly and all pipe connections are watertight. Develop a punch list for facility acceptance. Log the filtering practice's GPS coordinates and submit them for entry into the BMP maintenance tracking database.

DDOE's construction phase inspection checklist for filters and the Stormwater Facility Leak Test form can be found in Appendix K.

3.7.7 Filtering Maintenance Criteria

Maintenance of filters is required and involves several routine maintenance tasks, which are outlined in Table 3.29 below. A cleanup should be scheduled at least once a year to remove trash and floatables that accumulate in the pretreatment cells and filter bed. Frequent sediment cleanouts in the dry and wet sedimentation chambers are recommended every 1 to 3 years to maintain the function and performance of the filter. If the filter treats runoff from a stormwater hotspot, crews may need to test the filter bed media before disposing of the media and trapped pollutants. Petroleum hydrocarbon contaminated sand or filter cloth must be disposed of according to District solid waste disposal regulations. Testing is not needed if the filter does not receive runoff from a designated stormwater hotspot, in which case the media can be safely disposed of in a landfill.

Table 3.29 Typical Annual Maintenance Activities for Filtering Practices

Frequency	Maintenance Tasks
At least 4 times per growing season	▪ Mow grass filter strips and perimeter turf around surface sand filters. Maximum grass heights should be less than 12 inches.
2 times per year (may be more or less frequently depending on land use)	▪ Check to see if sediment accumulation in the sedimentation chamber has exceeded 6 inches. If so, schedule a cleanout.
Annually	▪ Conduct inspection and cleanup ▪ Dig a small test pit in the filter bed to determine whether the first 3 inches of sand are visibly discolored and need replacement. ▪ Check to see if inlets and flow splitters are clear of debris and are operating properly. ▪ Check concrete structures and outlets for any evidence of spalling, joint failure, leakage, corrosion, etc. ▪ Ensure that the filter bed is level and remove trash and debris from the filter bed. Sand or gravel covers should be raked to a depth of 3 inches.
Every 5 years	▪ Replace top sand layer. ▪ Till or aerate surface to improve infiltration/grass cover
As needed	▪ Remove blockages and obstructions from inflows. Trash collected on the grates protecting the inlets shall be removed regularly to ensure the inflow capacity of the BMP is preserved. ▪ Stabilize contributing drainage area and side-slopes to prevent erosion. Filters with a turf cover should have 95% vegetative cover.
Upon failure	▪ Corrective maintenance is required any time the sedimentation basin and sediment trap do not draw down completely after 72 hours (i.e., no standing water is allowed).

Maintenance Inspections. Regular inspections by a qualified professional are critical to schedule sediment removal operations, replace filter media, and relieve any surface clogging. Frequent inspections are especially needed for underground and perimeter filters, since they are out of sight and can be easily forgotten. Depending on the level of traffic or the particular land use, a filter system may either become clogged within a few months of normal rainfall or could possibly last several years with only routine maintenance. Maintenance inspections should be conducted within 24 hours following a storm that exceeds 1/2 inch of rainfall, to evaluate the condition and performance of the filtering practice.

Note: Without regular maintenance, reconditioning sand filters can be very expensive.

DDOE’s maintenance inspection checklists for filters and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A maintenance covenant is required for all stormwater management practices. The covenant specifies the property owner’s primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The covenant is attached to the deed of the property (see standard form, variations exist for scenarios where stormwater crosses property lines). A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. There may be a maintenance schedule on the drawings themselves or the plans may refer to the maintenance schedule (Exhibit C in the covenant).

Covenants are not required on government properties but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.7.8 Filtering Volume Compliance Calculations

Filtering practices receive 0 percent retention value. Filtering practices are an accepted total suspended solids (TSS) treatment practice for the amount of storage volume (Sv) provided by the BMP (Table 3.30).

Table 3.30 Filter Retention Value and Pollutant Removal

Retention Value	= 0
Accepted TSS Treatment Practice	Yes

The practice must be sized using the guidance detailed in Section 3.7.4.

3.7.9 References

Atlanta Regional Commission (ARC). 2001. Georgia Stormwater Management Manual, First Edition. Available online at: http://www.georgiastormwater.com

Claytor, R. and T. Schueler. 1996. Design of Stormwater Filtering Systems. Chesapeake Research Consortium and the Center for Watershed Protection. Ellicott City, MD. http://www.cwp.org/online-watershed-library?view=docman

Van Truong, Hung. 1989. The Sand Filter Water Quality Structure. D.C. Environmental Regulation Administration. Washington, DC.

Van Truong, Hung. 1993. Application of the Washington D.C. Sand Filter Water for Urban Runoff Control. Draft Report. Washington D.C. Environmental Regulations Administration. Washington, D.C. (30+ pages).

Virginia DCR Stormwater Design Specification No. 12: Filtering Practices Version 1.7. 2010.

3.8 Infiltration

Definition. Practices that capture and temporarily store the design storm volume before allowing it to infiltrate into the soil over a two day period. Design variants include:

I-1 Infiltration trench

I-2 Infiltration basin

Infiltration practices use temporary surface or underground storage to allow incoming stormwater runoff to exfiltrate into underlying soils. Runoff first passes through multiple pretreatment mechanisms to trap sediment and organic matter before it reaches the practice. As the stormwater penetrates the underlying soil, chemical and physical adsorption processes remove pollutants. Infiltration practices are suitable for use in residential and other urban areas where field measured soil infiltration rates are sufficient. To prevent possible groundwater contamination, infiltration must not be utilized at sites designated as stormwater hotspots.

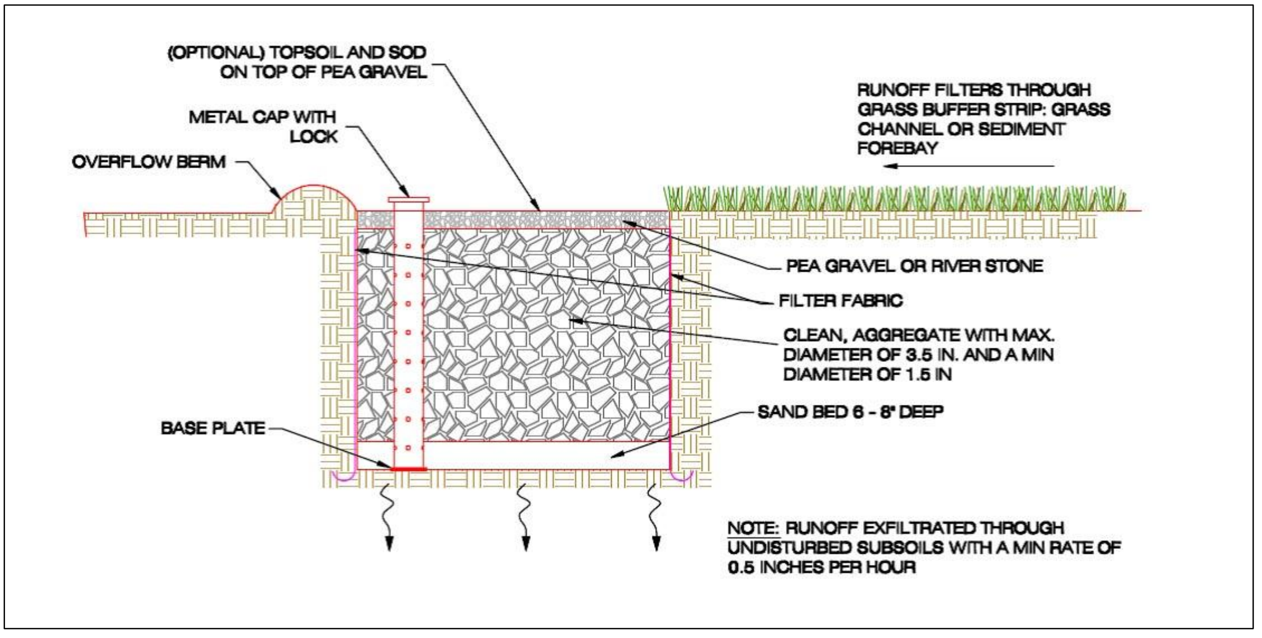

Figure 3.29 Example of an infiltration trench.

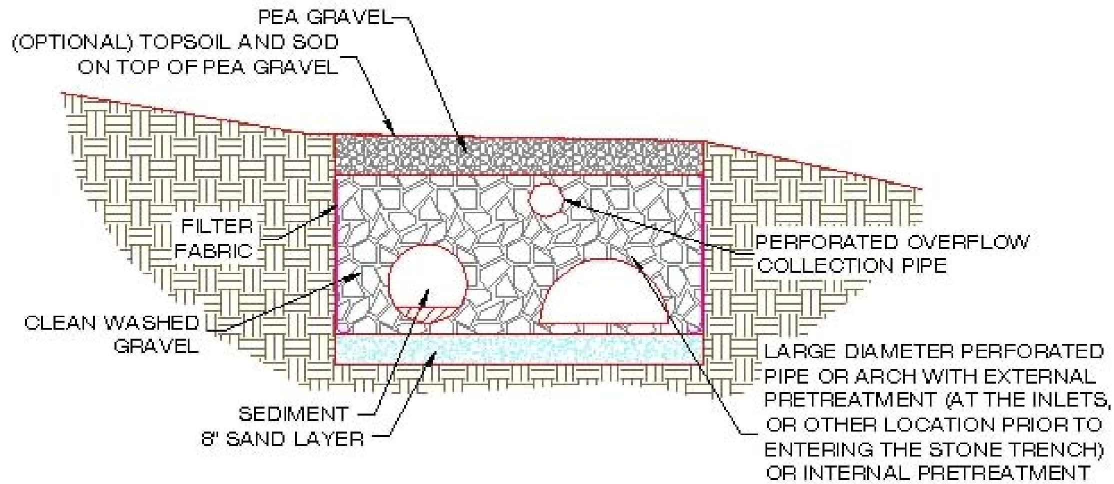

Figure 3.30 Infiltration section with supplemental pipe storage.

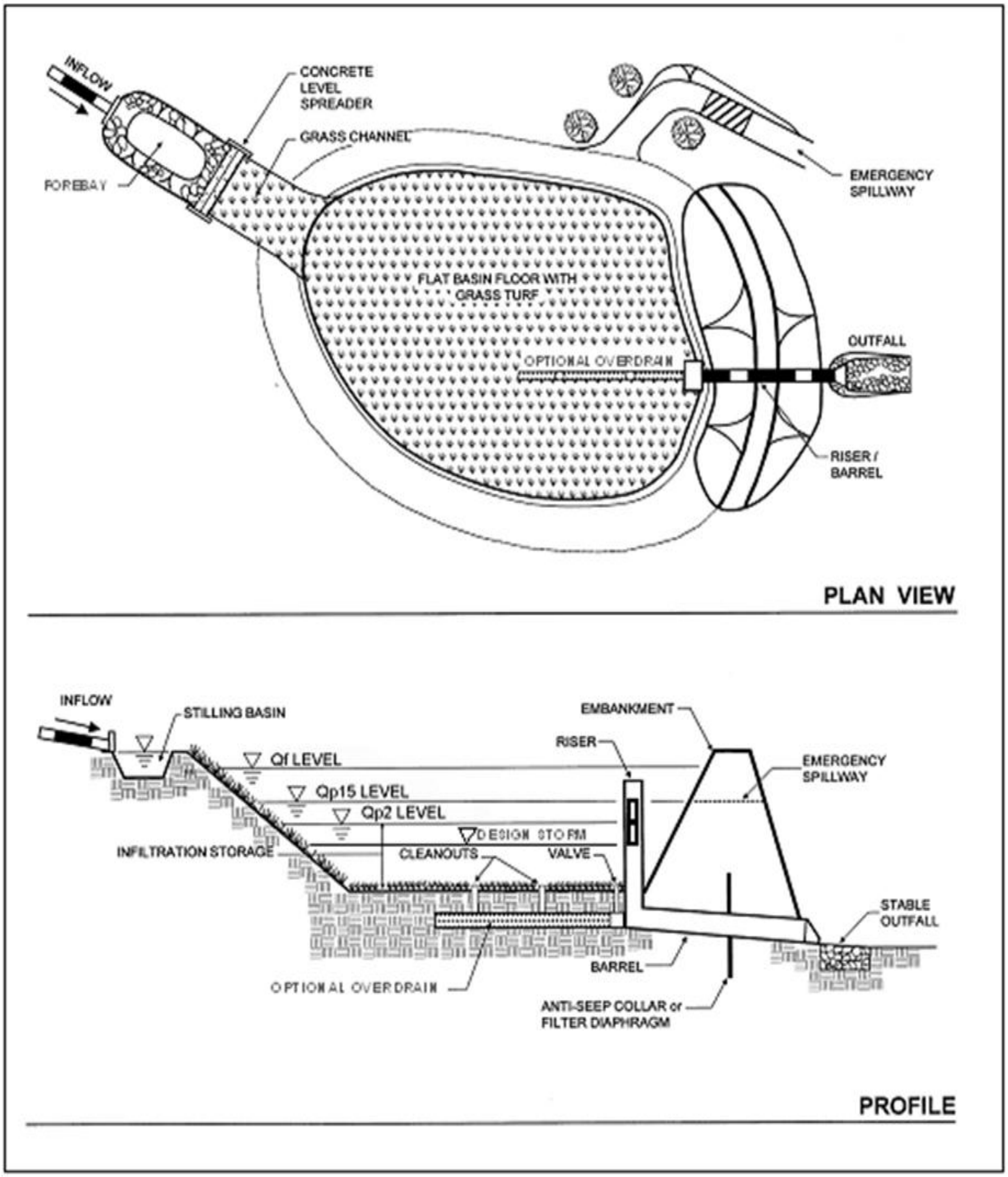

Figure 3.31 Example of an infiltration basin.

3.8.1 Infiltration Feasibility Criteria

Infiltration practices have very high storage and retention capabilities when sited and designed appropriately. Designers should evaluate the range of soil properties during initial site layout and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. In particular, areas of Hydrologic Soil Group A or B soils, shown on the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) soil surveys, should be considered as primary locations for infiltration practices. Additional information about soil and infiltration are described in more detail later in this section. During initial design phases, designers should carefully identify and evaluate constraints on infiltration, as follows:

Underground Injection Control for Class V Wells. In order for an infiltration practice to avoid classification as a Class V well, which is subject regulation under the Federal Underground Injection Control (UIC) program, the practice must be wider than the practice is deep. If an infiltration practice is "deeper than its widest surface dimension" or if it includes an underground distribution system, then it will likely be considered a Class V injection well. Class V injection wells are subject to permit approval by the U.S. Environmental Protection Agency (EPA). For more information on Class V injection wells and stormwater management, designers should consult http://water.epa.gov/type/groundwater/uic/class5/comply_minrequirements.cfm for EPA's minimum requirements.

Contributing Drainage Area. The maximum Contributing Drainage Area (CDA) to an individual infiltration practice should be less than 2 acres and as close to 100 percent impervious as possible. The design, pretreatment, and maintenance requirements will differ depending on the size of the infiltration practice.

Site Topography. Infiltration shall not be located on slopes greater than 6 percent, although check dams or other devices may be employed to reduce the effective slope of the practice. Further, unless slope stability calculations demonstrate otherwise, infiltration practices should be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20 percent.

Minimum Hydraulic Head. Two or more feet of head may be needed to promote flow through infiltration practices.

Minimum Depth to Water Table or Bedrock. A minimum vertical distance of 2 feet must be provided between the bottom of the infiltration practice and the seasonal high water table or bedrock layer.

Soils. Initially, soil infiltration rates can be estimated from NRCS soil data, but designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix O.

Use on Urban Fill Soils/Redevelopment Sites. Sites that have been previously graded or disturbed do not typically retain their original soil permeability due to compaction. Therefore, such sites are often not good candidates for infiltration practices unless the geotechnical investigation shows that a sufficient infiltration rate exists.

Dry Weather Flows. Infiltration practices should not be used on sites receiving regular dry-weather flows from sump pumps, irrigation water, chlorinated wash-water, or flows other than stormwater.

Setbacks. Infiltration practices must not be hydraulically connected to structure foundations or pavement, in order to avoid harmful seepage. Setbacks to structures vary must be at least 10 feet and adequate water-proofing protection must be provided for foundations and basements. Where the 10-foot setback is not possible, an impermeable liner may be used along the sides of the infiltration area (extending from the surface to the bottom of the practice).

All setbacks must be verified by a professional geotechnical engineer registered in the District of Columbia.

Proximity to Utilities. Interference with underground utilities should be avoided, if possible. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the public right-of-way. Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the infiltration BMP. For an infiltration BMP in the public right-of-way a consolidated presentation of the various utility offset recommendations can be found in Chapter 33.14.5 of the District of Columbia Department of Transportation Design and Engineering Manual, latest edition. Consult the District of Columbia Water and Sewer Authority (DC Water) Green Infrastructure Utility Protection Guidelines, latest edition, for water and sewer line recommendations. Where conflicts cannot be avoided, follow these guidelines:

- Consider altering the location or sizing of the infiltration BMP to avoid or minimize the utility conflict. Consider an alternate BMP type to avoid conflict.
- Use design features to mitigate the impacts of conflicts that may arise by allowing the infiltration BMP and the utility to coexist. The infiltration BMP design may need to incorporate impervious areas, through geotextiles or compaction, to protect utility crossings. Other a key design feature may need to be moved or added or deleted
- Work with the utility to evaluate the relocation of the existing utility and install the optimum placement and sizing of the infiltration BMP.
- If utility functionality, longevity and vehicular access to manholes can be assured accept the infiltration BMP design and location with the existing utility. Incorporate into the infiltration BMP design sufficient soil coverage over the utility or general clearances or other features such as an impermeable linear to assure all entities the conflict is limited to maintenance.

Note: When accepting utility conflict into the infiltration BMP location and design, it is understood the infiltration BMP will be temporarily impacted during utility work but the utility will replace the infiltration BMP or, alternatively, install a functionally comparable infiltration BMP according to the specifications in the current version of this Stormwater Management Guidebook. If the infiltration BMP is located in the public right-of-way the infiltration BMP restoration will also conform with the District of Columbia Department of Transportation Design and Engineering Manual with special attention to Chapter 33, Chapter 47, and the Design and Engineering Manual supplements for Low Impact Development and Green Infrastructure Standards and Specifications.

Hotspots and High Loading Situations. Infiltration practices are not intended to treat sites with high sediment or trash or debris loads, because such loads will cause the practice to clog and fail. Infiltration practices must be avoided at potential stormwater hotspots that pose a risk of groundwater contamination. For a list of potential stormwater hotspot operations, consult Appendix P.

On sites with existing contaminated soils, as indicated in Appendix O, infiltration is not allowed.

3.8.2 Infiltration Conveyance Criteria

The nature of the conveyance and overflow to an infiltration practice depends on the scale of infiltration and whether the facility is on-line or off-line. Where possible, conventional infiltration practices should be designed off-line to avoid damage from the erosive velocities of larger design storms. If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice shall be designed as an off-line practice. Pretreatment shall be provided for storm drain pipes systems discharging directly to infiltration systems.

Off-line Infiltration. Overflows can either be diverted from entering the infiltration practice or dealt with via an overflow inlet. Optional overflow methods include the following:

- Utilize a low-flow diversion or flow splitter at the inlet to allow only the design Stormwater Retention Volume (SWRv) 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 (further guidance on determining the peak flow rate will be necessary in order to ensure proper design of the diversion structure).
- Use landscaping type inlets or standpipes with trash guards as overflow devices.

On-line Infiltration. An overflow structure must be incorporated into on-line designs to safely convey larger storms through the infiltration area. Mechanisms such as elevated drop inlets and overflow weirs are examples of how to direct high flows to a non-erosive down-slope overflow channel, stabilized water course, or storm sewer system designed to convey the 15-year design storm.

3.8.3 Infiltration Pretreatment Criteria

Every infiltration system shall have pretreatment mechanisms to protect the long term integrity of the infiltration rate. One of the following techniques must be installed to pretreat 100 percent of the inflow in every facility:

- Grass channel
- Grass filter strip (minimum 20 feet and only if sheet flow is established and maintained)
- Forebay (must accommodate a minimum 25 percent of the design storm volume; if the infiltration rate for the underlying soils is greater than 2 inches per hour, the forebay volume shall be increased to a minimum of 50 percent of the design storm volume)

- Gravel diaphragm (minimum 1 foot deep and 2 feet wide and only if sheet flow is established and maintained)
- Filter system (see Section 3.7 Stormwater Filtering Systems) If using a filter system as a pretreatment facility, the sand filter will not require its own separate pretreatment facility.
- A proprietary structure with demonstrated capability of reducing sediment and hydrocarbons may be used to provide pretreatment. Refer to Section 3.13 Proprietary Practices and Appendix S for information on approved proprietary structures.

If the basin serves a CDA greater than 20,000 square feet, a forebay, filter system, or proprietary practice must be used for pretreatment.

Exit velocities from the pretreatment chamber shall not be erosive (above 6 fps) during the 15-year design storm and flow from the pretreatment chamber should be evenly distributed across the width of the practice (e.g., using a level spreader).

3.8.4 Infiltration Design Criteria

Geometry. Where possible, infiltration practices should be designed to be wider than they are deep, to avoid classification as a class V injection well. For more information on Class V wells see http://water.epa.gov/type/groundwater/uic/class5/index.cfm.

Practice Slope. The bottom of an infiltration practice should be flat (i.e., 0 percent longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater.

Infiltration Basin Geometry. The maximum vertical depth to which runoff may be ponded over an infiltration basin is 24 inches. The side-slopes should be no steeper than 4H:1V

Surface Cover (optional). Designers may choose to install a layer of topsoil and grass above the infiltration practice.

Surface Stone. A 3-inch layer of clean, washed river stone or No. 8 or 89 stone should be installed over the stone layer.

Stone Layer. Stone layers must consist of clean, washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches.

Underground Storage (optional). In the underground mode, runoff is stored in the voids of the stones and infiltrates into the underlying soil matrix. Perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials can be used in conjunction with the stone to increase the available temporary underground storage. In some instances, a combination of filtration and infiltration cells can be installed in the floor of a dry extended detention (ED) pond.

Overflow Collection Pipe (Overdrain). An optional overflow collection pipe can be installed in the stone layer to convey collected runoff from larger storm events to a downstream conveyance system.

Trench Bottom. To protect the bottom of an infiltration trench from intrusion by underlying soils, a sand layer must be used. The underlying native soils must be separated from the stone layer by a 6- to 8-inch layer of coarse sand (e.g., ASTM C 33, 0.02-0.04 inch).

Geotextile Fabric. An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used. This layer should be applied only to the sides of the practice.

Material Specifications. Recommended material specifications for infiltration areas are shown in Table 3.31.

Table 3.31 Infiltration Material Specifications

Material	Specification	Notes
Surface Layer (optional)	Topsoil and grass layer	
Surface Stone	Install a 3-inch layer of river stone or pea gravel.	Provides an attractive surface cover that can suppress weed growth.
Stone Layer	Clean, aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches.	
Observation Well	Install a vertical 6-inch Schedule 40 PVC perforated pipe, with a lockable cap and anchor plate.	Install one per 50 feet of length of infiltration practice.
Overflow Collection Pipe (optional)	Use 4- or 6-inch rigid schedule 40 PVC pipe, with 3/8-inch perforations at 6 inches on center.	
Trench Bottom	Install a 6- to 8-inch sand layer (e.g., ASTM C 33, 0.02-0.04 inch)	
Geotextile Fabric (sides only)	An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used.	

Practice Sizing. The proper approach for designing infiltration practices is to avoid forcing a large amount of infiltration into a small area. Therefore, individual infiltration practices that are limited in size due to soil permeability and available space need not be sized to achieve the full design storm volume (SWRv) for the contributing drainage area, as long as other stormwater treatment practices are applied at the site to meet the remainder of the design storm volume.

Several equations (see following page) are needed to size infiltration practices. The first equations establish the maximum depth of the infiltration practice, depending on whether it is a surface basin (Equation 3.9) or trench with an underground reservoir (Equation 3.10).

Equation 3.9 Maximum Surface Basin Depth for Infiltration Basins

$$d_{max} = \frac{i}{2} \times t_d$$

Equation 3.10 Maximum Underground Reservoir Depth for Infiltration Trenches

$$d_{\max} = \frac{\left(\frac{i}{2} \times t_d\right)}{\eta_r}$$

where:

d_{max}	=	maximum depth of the infiltration practice (ft)
i	=	field-verified (actual) infiltration rate for the native soils (ft/day)
t_d	=	maximum drawdown time (day) (normally 3 days)
η_r	=	available porosity of the stone reservoir (assume 0.35)

These equations make the following design assumptions:

- **Conservative Infiltration Rates.** For design purposes, the field-tested subgrade soil infiltration rate (i) is divided by 2 as a factor of safety to account for potential compaction during construction and to approximate long term infiltration rates. On-site infiltration investigations must be conducted to establish the actual infiltration capacity of underlying soils, using the methods presented in Appendix O.
- **Stone Layer Porosity.** A porosity value of 0.35 shall be used in the design of stone reservoirs, although a larger value may be used if perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials are installed within the reservoir.
- **Rapid Drawdown.** Infiltration practices must be sized so that the design volume infiltrates within 72 hours, to prevent nuisance ponding conditions.

Designers should compare these results to the maximum allowable depths in Table 3.32 and use whichever value is less for subsequent design.

Table 3.32 Maximum Facility Depth for Infiltration Practices

Mode of Entry	Scale of Infiltration		
	Micro Infiltration ($250–2,500\ ft^2$)	**Small Scale Infiltration ($2,500–20,000\ ft^2$)**	**Conventional Infiltration ($20,000–100,000\ ft^2$)**
Surface Basin	1.0	1.5	2.0
Underground Reservoir	3.0	5.0	varies

Once the maximum depth is known, calculate the surface area needed for an infiltration practice using Equation 3.11 or Equation 3.12.

Equation 3.11 Surface Basin Surface Area for Infiltration Basins

$$SA = \frac{DesignStorm}{d + \left(\frac{i}{2} \times t_f\right)}$$

Equation 3.12 Underground Reservoir Surface Area for Infiltration Trenches

$$SA = \frac{DesignStorm}{(\eta_r \times d) + (0.5 \times i \times t_f)}$$

where:

SA	=	surface area (ft^2)
DesignStorm	=	*SWRv* or other design storm volume (ft^3) (e.g., portion of the *SWRv*)
η_r	=	available porosity of the stone reservoir (assume 0.35)
d	=	infiltration depth (ft) (maximum depends on the scale of infiltration and the results of Equation 3.9 or 3.10)
i	=	field-verified (actual) infiltration rate for the native soils (ft/day)
tf	=	time to fill the infiltration facility (days) (typically 2 hours, or 0.083 days)

The storage volume (*Sv*) captured by the infiltration practice is defined as the volume of water that is fully infiltrated through the practice (no overflow). Designers may choose to infiltrate less than the full design storm (*SWRv*). In this case, the design volume captured must be treated as the storage volume, *Sv* of the practice (see Section 3.8.8 Infiltration Stormwater Compliance Calculations). *Sv* can be determined by rearranging Equation 3.11 and Equation 3.12 to yield Equation 3.13 and Equation 3.15.

Equation 3.13 Storage Volume Calculation for Surface Basin Area for Infiltration Basins

$$Sv = SA \times \left[d + \left(\frac{i}{2} \times t_f\right)\right]$$

Equation 3.14 Storage Volume Calculation for Underground Reservoir Surface Area for Infiltration Trenches

$$Sv = SA \times \left[(\eta_r \times d) + \left(\frac{i}{2} \times t_f\right)\right]$$

Infiltration practices can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer, any perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials installed within the reservoir, expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

3.8.5 Infiltration Landscaping Criteria

Infiltration trenches can be effectively integrated into the site plan and aesthetically designed with adjacent native landscaping or turf cover, subject to the following additional design considerations:

- Infiltration practices should not be installed until all up-gradient construction is completed and pervious areas are stabilized with dense and healthy vegetation, unless the practice can be kept off-line so it receives no runoff until construction and stabilization is complete.
- Vegetation associated with the infiltration practice buffers should be regularly maintained to limit organic matter in the infiltration device and maintain enough vegetation to prevent soil erosion from occurring.

3.8.6 Infiltration Construction Sequence

Infiltration practices are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the practice. In addition, loading from heavy construction equipment can result in compaction of the soil, which can then reduce the soil's infiltration rate. For this reason, a careful construction sequence needs to be followed.

During site construction, the following protective measures are absolutely critical:

- All areas proposed for infiltration practices should be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.
- Avoid excessive compaction by preventing construction equipment and vehicles from traveling over the proposed location of the infiltration practice. To accomplish this, areas intended to infiltrate runoff must remain outside the limit of disturbance during construction.
- When this is unavoidable, there are several possible outcomes for the impacted area.
    - If excavation at the impacted area can be restricted then remediation can be achieved with deep tilling practices. This is only possible if in-situ soils are not disturbed below 2 feet above the final design elevation of the bottom of the infiltration practice. In this case, when heavy equipment activity has ceased, the area is excavated to grade, and the impacted area must be tilled a minimum of 12 inches (30 cm) below the bottom of the infiltration practice.

  - Alternatively, if it is infeasible to keep the proposed infiltration practice outside of the limits of disturbance, and excavation of the area cannot be restricted, then infiltration tests will be required prior to installation of the permeable pavement to ensure that the design infiltration rate is still present. If tests reveal the loss of design infiltration rates then deep tilling practices may be used in an effort to restore those rates. In this case further testing must be done to establish design rates exist before the infiltration practice can be installed.
  - Finally, if it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, and excavation of the area cannot be restricted, and infiltration tests reveal design rates cannot be restored, then a resubmission of the SWMP will be required.
- Any area of the site intended ultimately to be an infiltration practice must not be used as the site of a temporary sediment trap or basin. If locating a sediment trap or basin on an area intended for infiltration is unavoidable, the outcomes are parallel to those discussed for heavy equipment compaction. If it is possible to restrict the invert of the sediment trap or basin at least 2 feet above the final design elevation of the bottom of the proposed infiltration practice then remediation can be achieved with proper removal of trapped sediments and deep tilling practices. An alternate approach to deep tilling is to use an impermeable linear to protect the in-situ soils from sedimentation while the sediment trap or basin is in use. In each case, all sediment deposits must carefully removed prior to installing the infiltration practice.
- Keep the infiltration practice “off-line” until construction is complete. Prevent sediment from entering the infiltration site by using super silt fence, diversion berms, or other means. In the soil erosion and sediment control plan, indicate the earliest time at which stormwater runoff may be directed to a conventional infiltration basin. The soil erosion and sediment control plan must also indicate the specific methods to be used to temporarily keep runoff from the infiltration site.
- Upland drainage areas need to be completely stabilized with a well-established layer of vegetation prior to commencing excavation for an infiltration practice.

Infiltration Installation. The actual installation of an infiltration practice is done using the following steps:

Step 1: **Avoid Impact of Heavy Installation Equipment.** Excavate the infiltration practice to the design dimensions from the side using a backhoe or excavator. The floor of the pit should be completely level, but equipment should be kept off the floor area to prevent soil compaction.

Step 2: **Hang Geotextile Walls.** Install geotextile fabric on the trench sides. Large tree roots should be trimmed flush with the sides of infiltration trenches to prevent puncturing or tearing of the geotextile fabric during subsequent installation procedures. When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the trench and for a 6-inch minimum overlap at the top of the trench. The geotextile fabric itself should be tucked under the sand layer on the bottom of the infiltration trench. Stones or other anchoring objects should be placed on the fabric at the trench sides, to keep the trench open during windy periods. Voids may occur between the fabric and the excavated sides of a trench. Natural soils should be placed in all voids, to ensure the fabric conforms smoothly to the sides of excavation.

Step 3: **Promote Infiltration Rate.** Scarify the bottom of the infiltration practice, and spread 6 inches of sand on the bottom as a filter layer.

Step 4: **Observation Wells.** Anchor the observation well(s) and add stone to the practice in 1-foot lifts.

Step 5: **Stabilize Surrounding Area.** Use sod, where applicable, to establish a dense turf cover for at least 10 feet around the sides of the infiltration practice, to reduce erosion and sloughing.

Construction Supervision. Supervision during construction is recommended to ensure that the infiltration practice is built in accordance with the approved design and this specification. Qualified individuals should use detailed inspection checklists to include sign-offs at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intentions.

DDOE's construction phase inspection checklist for infiltration practices can be found in Appendix K.

3.8.7 Infiltration Maintenance Criteria

Maintenance is a crucial and required element that ensures the long-term performance of infiltration practices. The most frequently cited maintenance problem for infiltration practices is clogging of the stone by organic matter and sediment. The following design features can minimize the risk of clogging:

Stabilized CDA. Infiltration systems may not receive runoff until the entire contributing drainage area has been completely stabilized.

Observation Well. Infiltration practices must include an observation well, consisting of an anchored 6-inch diameter perforated PVC pipe fitted with a lockable cap installed flush with the ground surface, to facilitate periodic inspection and maintenance.

No Geotextile Fabric on Bottom. Avoid installing geotextile fabric along the bottom of infiltration practices. Experience has shown that geotextile fabric is prone to clogging. However, permeable geotextile fabric should be installed on the trench sides to prevent soil piping.

Direct Maintenance Access. Access must be provided to allow personnel and heavy equipment to perform atypical maintenance tasks, such as practice reconstruction or rehabilitation. While a turf cover is permissible for small-scale infiltration practices, the surface must never be covered by an impermeable material, such as asphalt or concrete.

Maintenance Inspections. Effective long-term operation of infiltration practices requires a dedicated and routine maintenance inspection schedule with clear guidelines and schedules, as shown in Table 3.33 below. Where possible, facility maintenance should be integrated into routine landscaping maintenance tasks.

Table 3.33 Typical Maintenance Activities for Infiltration Practices

Schedule	Maintenance Activity
Quarterly	▪ Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. ▪ Ensure that the contributing drainage area is stabilized. Perform spot-reseeding if where needed. ▪ Remove sediment and oil/grease from inlets, pretreatment devices, flow diversion structures, and overflow structures. ▪ Repair undercut and eroded areas at inflow and outflow structures.
Semi-annual inspection	▪ Check observation wells 3 days after a storm event in excess of 1/2 inch in depth. Standing water observed in the well after three days is a clear indication of clogging. ▪ Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.
Annually	▪ Clean out accumulated sediment from the pretreatment cell.
As needed	▪ Replace pea gravel/topsoil and top surface geotextile fabric (when clogged). ▪ Mow vegetated filter strips as necessary and remove the clippings.

It is highly recommended that a qualified professional conduct annual site inspections for infiltration practices to ensure the practice performance and longevity of infiltration practices.

DDOE’s maintenance inspection checklist for infiltration systems and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner’s primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.8.8 Infiltration Stormwater Compliance Calculations

Infiltration practices receive 100 percent retention value for the amount of storage volume (Sv) provided by the practice (Table 3.34). Since the practice gets 100 percent retention value, it is not considered an accepted total suspended solids (TSS) treatment practice.

Table 3.34 Infiltration Retention Value and Pollutant Removal

Retention Value	= *Sv*
Accepted TSS Treatment Practice	N/A

The practice must be sized using the guidance detailed in Section 3.8.4. Infiltration Design Criteria.

Infiltration practices also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the Sv or Retention Value from the total runoff volume for the 2-year, 15-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a Reduced Natural Resource Conservation Service (NRCS) Curve Number for the site or drainage area. The Reduced Curve Number can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

3.8.9 References

Virginia DCR Stormwater Design Specification No. 8: Bioretention Version 1.8. 2010.

3.9 Open Channel Systems

Definition. Vegetated open channels that are designed to capture and treat or convey the design storm volume (Stormwater Retention Volume (SWRv)). Design variants include:

O-1 Grass channels

O-2 Dry swales/bioswales

O-3 Wet swales

Open channel systems shall not be designed to provide stormwater detention except under extremely unusual conditions. Open channel systems must generally be combined with a separate facility to meet these requirements.

Grass channels (O-1) can provide a modest amount of runoff filtering and volume attenuation within the stormwater conveyance system resulting in the delivery of less runoff and 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. Grass channels, however, are not capable of providing the same stormwater functions as dry swales as they lack the storage volume associated with the engineered soil media. Their retention performance can be boosted when compost amendments are added to the bottom of the swale (see Appendix J). 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.

Dry swales (O-2), also known as bioswales, are essentially bioretention cells that are shallower, configured as linear channels, and covered with turf or other surface material (other than mulch and ornamental plants). The dry swale is a soil filter system that temporarily stores and then filters the desired design storm volume. Dry swales rely on a premixed soil media filter below the channel that is similar to that used for bioretention. If soils are extremely permeable, runoff infiltrates into underlying soils. In most cases, however, the runoff treated by the soil media flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale, beneath the filter media. Dry swales may appear as simple grass channels with the same shape and turf cover, while others may have more elaborate landscaping. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees.

Wet swales (O-3) can provide a modest amount of runoff filtering within the conveyance. These linear wetland cells often intercept shallow groundwater to maintain a wetland plant community. The saturated soil and wetland vegetation provide an ideal environment for gravitational settling, biological uptake, and microbial activity. On-line or off-line cells are formed within the channel to create saturated soil or shallow standing water conditions (typically less than 6 inches deep).

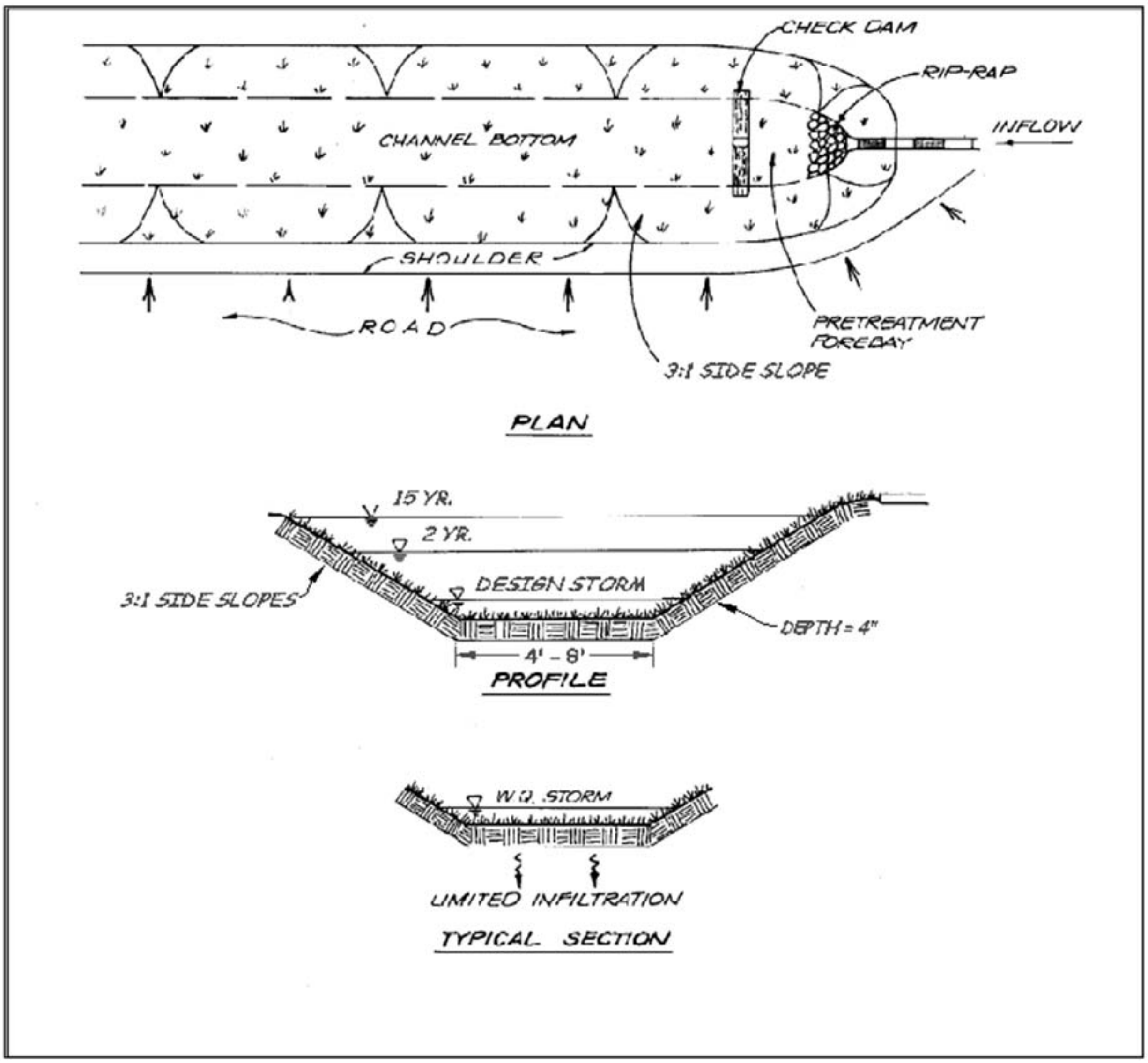

Figure 3.32 Grass channel typical plan, profile, and section views (O-1).

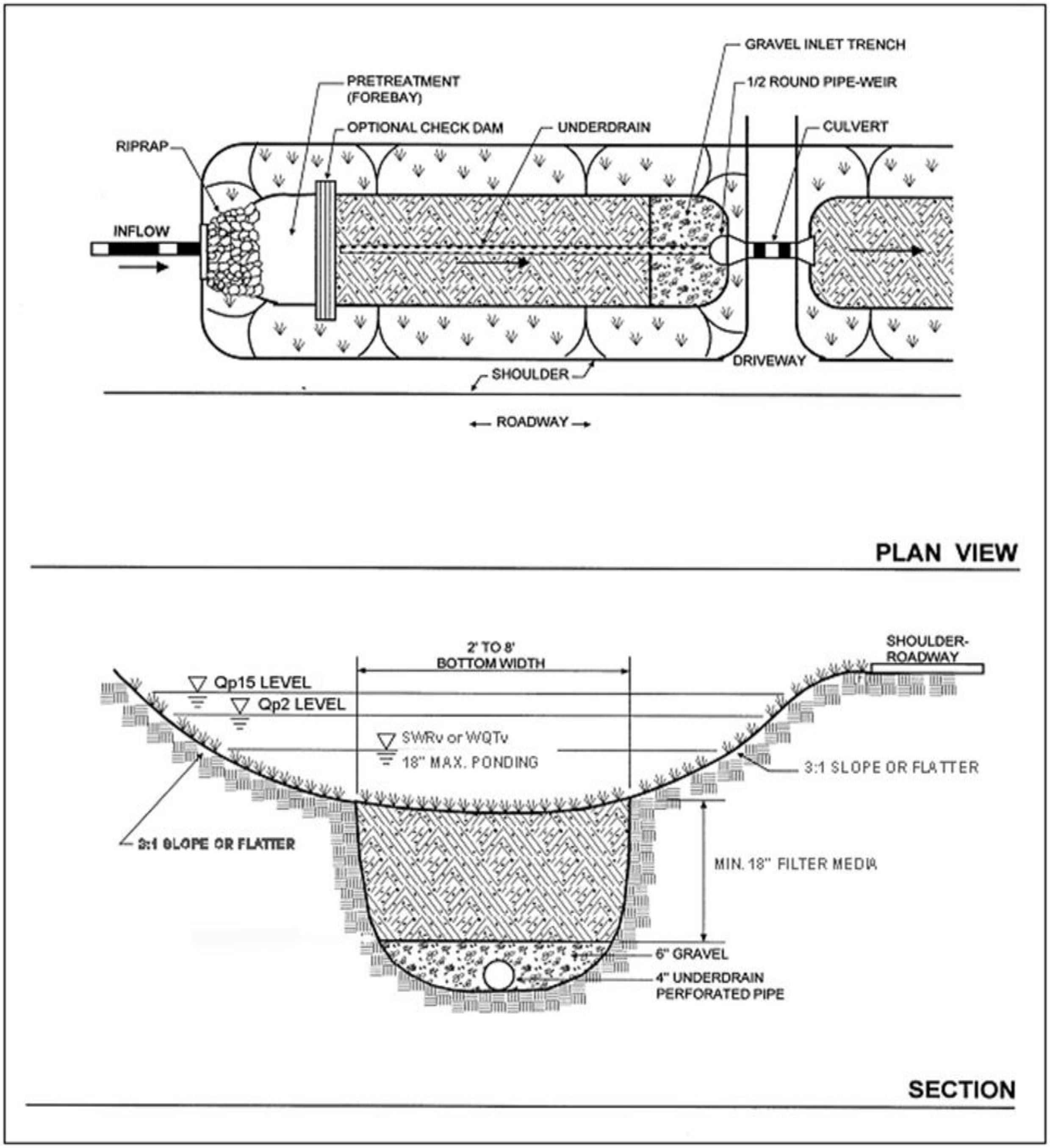

Figure 3.33 Example of a dry swale (O-2).

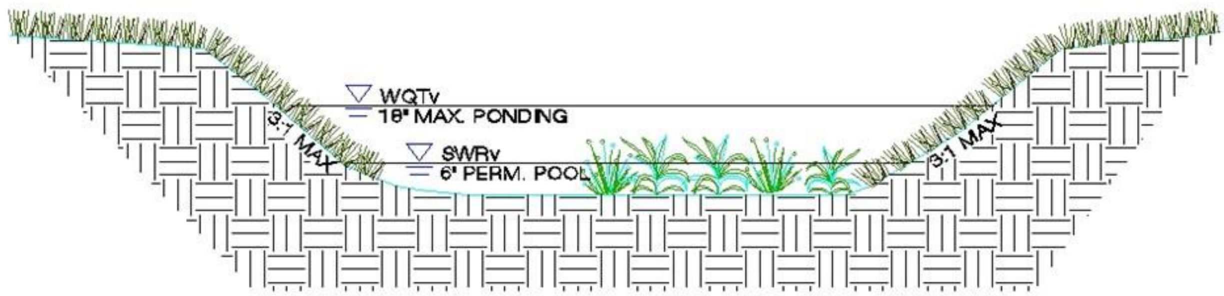

Figure 3.34 Example of a wet swale (O-3).

3.9.1 Open Channel Feasibility Criteria

Open channel systems are primarily applicable for land uses, such as roads, highways, and residential development. Some key feasibility issues for open channels include the following:

Contributing Drainage Area. The maximum contributing drainage area to an open channel should be 2.5 acres, preferably less. When open channels treat and convey runoff from drainage areas greater than 2.5 acres, the velocity and flow depth through the channel often becomes too great to treat runoff or prevent erosion in the channel. The design criteria for maximum channel velocity and depth are applied along the entire length (see Section 3.9.4 Open Channel Design Criteria).

Available Space. Open channel footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Dry Swales should be approximately 3 to 10 percent of the size of the contributing drainage area, depending on the amount of impervious cover. Wet swale footprints usually cover about 5 to 15 percent of their contributing drainage area. 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. However, the benefit of the retention may reduce the footprint requirements for stormwater management elsewhere on the development site.

Site Topography. Grass channels and wet swales should be used on sites with longitudinal slopes of less than 4 percent. Check dams can be used to reduce the effective slope of the channel and lengthen the contact time to enhance filtering and/or infiltration. Longitudinal slopes of less than 2 percent are ideal and may eliminate the need for check dams. However, channels designed with longitudinal slopes of less than 1 percent should be monitored carefully during construction to ensure a continuous grade, in order to avoid flat areas with pockets of standing water.

For dry swales, check dams will be necessary regardless of the longitudinal slope to create the necessary ponding volume.

Land Uses. Open channels can be used in residential, commercial, or institutional development settings.

When open channels are used for both conveyance and water quality treatment, they should be applied only in linear configurations parallel to the contributing impervious cover, such as roads and small parking areas. The linear nature of open channels makes them well-suited to treat highway or low- and medium-density residential road runoff, if there is adequate right-of-way width and distance between driveways. Typical applications of open channels include the following, as long as drainage area limitations and design criteria can be met:

- Within a roadway right-of-way;
- Along the margins of small parking lots;
- Oriented from the roof (downspout discharge) to the street;
- Disconnecting small impervious areas; and
- Used to treat the managed turf areas of sports fields, golf courses, and other turf-intensive land uses, or to treat drainage areas with both impervious and managed turf cover (such as residential streets and yards).

Open channels are not recommended when residential density exceeds more than 4 dwelling units per acre, due to a lack of available land and the frequency of driveway crossings along the channel.

Open channels can also provide pretreatment for other stormwater treatment practices.

Available Hydraulic Head. A minimum amount of hydraulic head is needed to implement open channels in order to ensure positive drainage and conveyance through the channel. The hydraulic head for wet swales and grass channels is measured as the elevation difference between the channel inflow and outflow point. The hydraulic head for dry swales is measured as the elevation difference between the inflow point and the storm drain invert. Dry swales typically require 3 to 5 feet of hydraulic head since they have both a filter bed and underdrain.

Hydraulic Capacity. Open channels are typically designed as on-line practices which must be designed with enough capacity to (1) convey runoff from the 2-year and 15-year design storms at non-erosive velocities, and (2) contain the 15-year flow within the banks of the swale. This means that the swale's surface dimensions are more often determined by the need to pass the 15-year storm events, which can be a constraint in the siting of open channels within existing rights-of-way (e.g., constrained by sidewalks).

Depth to Water Table. The bottom of dry swales and grass channels must be at least 2 feet above the seasonally high groundwater table, to ensure that groundwater does not intersect the filter bed, since this could lead to groundwater contamination or practice failure. It is permissible for wet swales to intersect the water table.

Soils. Soil conditions do not constrain the use of open channels, although they do dictate some design considerations:

- Dry swales in soils with infiltration rates of less than 1/2 inch per hour may need an underdrain. Designers must verify site-specific soil permeability at the proposed location using the methods for on-site soil investigation presented in Appendix O, in order to eliminate the requirements for a dry swale underdrain.
- Grass channels situated on low-permeability soils may incorporate compost amendments in order to improve performance (see Appendix J).
- Wet swales work best on the more impermeable Hydrologic Soil Group (HSG) C or D soils.
- Infill soil locations, geotechnical investigations are required to determine if the use of an impermeable liner and underdrain are necessary for open channel designs.

Utilities. Typically, utilities can cross linear channels if they are specially protected (e.g., double-casing). Interference with underground utilities should be avoided, if possible. When large site development is undertaken, the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the public right-of-way. Where conflicts cannot be avoided, these guidelines shall be followed:

- Consult with each utility company on recommended offsets that will allow utility maintenance work with minimal disturbance to the BMP.
- Whenever possible, coordinate with utility companies to allow them to replace or relocate their aging infrastructure while BMPs are being implemented.
- BMP and utility conflicts will be a common occurrence in public right-of-way projects. However, the standard solution to utility conflict should be the acceptance of conflict provided sufficient soil coverage over the utility can be assured.
- Additionally, when accepting utility conflict into the BMP design, it is understood that the BMP will be temporarily impacted during utility maintenance but restored to its original condition.

Avoidance of Irrigation or Baseflow. Open channels should be located so as to avoid inputs of springs, irrigation systems, chlorinated wash-water, or other dry weather flows.

Setbacks. To avoid the risk of seepage, open channels must not be hydraulically connected to structure foundations. Setbacks to structures must be at least 10 feet and adequate water-proofing protection must be provided for foundations and basements.

Hotspot Land Use. Runoff from hotspot land uses must not be treated with infiltrating dry swales due to the potential interaction with the water table and the risk that hydrocarbons, trace metals, and other toxic pollutants could migrate into the groundwater. An impermeable liner must be used for filtration of hotspot runoff for dry swales. Grass channels can typically be used to convey runoff from stormwater hotspots, but they do not qualify as a hotspot treatment mechanism. Wet swales are not recommended to treat stormwater hotspots, due to the potential interaction with the water table and the risk that hydrocarbons, trace metals, and other toxic pollutants could migrate into the groundwater. For a list of designated stormwater hotspot operations, consult Appendix P.

On sites with existing contaminated soils, as indicated in Appendix P, infiltration is not allowed. Dry and wet swales must include an impermeable liner.

3.9.2 Open Channel Conveyance Criteria

The bottom width and slope of a grass channel must be designed such that the velocity of flow from the design storm provides a minimum hydraulic residence time (average travel time for a particle of water through a waterbody) of 9 minutes for the peak flows from the SWRv or design storm. Check dams may be used to achieve the needed retention volume, as well as to reduce the flow velocity. Check dams must be spaced based on channel slope and ponding requirements, consistent with the criteria in Section 3.9.4 Open Channel Design Criteria.

Open channels must also convey the 2- and 15-year storms at non-erosive velocities (generally less than 6 fps) for the soil and vegetative cover provided. The final designed channel shall provide 1 foot minimum freeboard above the designated water surface profile of the channel. The analysis must evaluate the flow profile through the channel at normal depth, as well as the flow depth over top of the check dams.

3.9.3 Open Channel Pretreatment Criteria

Pretreatment is required for open channels to dissipate energy, trap sediments, and slow down the runoff velocity.

The selection of a pretreatment method depends on whether the channel will experience sheet flow or concentrated flow. Several options are as follows:

- **Check Dams (channel flow).** These energy dissipation devices are acceptable as pretreatment on small open channels with drainage areas of less than 1 acre. The most common form is the use of wooden or stone check dams. The pretreatment volume stored must be 15 percent of the design volume.
- **Tree Check Dams (channel flow).** These are street tree mounds that are placed within the bottom of grass channels up to an elevation of 9 to 12 inches above the channel invert. One side has a gravel or river stone bypass to allow runoff to percolate through (Cappiella et al, 2006). The pretreatment volume stored must be 15 percent of the design volume.
- **Grass Filter Strip (sheet flow).** Grass filter strips extend from the edge of the pavement to the bottom of the open channel at a slope of 5:1 or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5 percent (20:1) cross slope and 3:1 or flatter side slopes on the open channel.

- **Gravel or Stone Diaphragm (sheet flow).** The gravel diaphragm is located at the edge of the pavement or the edge of the roadway shoulder and extends the length of the channel to pretreat lateral runoff. This requires a 2 to 4 inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The stone must be sized according to the expected rate of discharge.
- **Gravel or Stone Flow Spreaders (concentrated flow).** The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2 to 4 inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the channel.
- **Initial Sediment Forebay (channel flow).** This grassed cell is located at the upper end of the open channel segment with a recommended 2:1 length to width ratio and a storage volume equivalent to at least 15 percent of the total design storm volume. If the volume of the forebay will be included as part of the dry swale storage volume, the forebay must de-water between storm events. It cannot have a permanent ponded volume.

3.9.4 Open Channel Design Criteria

Channel Geometry. Design guidance regarding the geometry and layout of open channels is provided below:

- Open channels should generally be aligned adjacent to and the same length as the contributing drainage area identified for treatment.
- Open channels should be designed with a trapezoidal or parabolic cross section. A parabolic shape is preferred for aesthetic, maintenance, and hydraulic reasons.
- The bottom width of the channel should be between 4 to 8 feet wide to ensure that an adequate surface area exists along the bottom of the swale for filtering. If a channel will be wider than 8 feet, the designer must incorporate benches, check dams, level spreaders, or multi-level cross sections to prevent braiding and erosion along the channel bottom.
- Open-channel side slopes should be no steeper than 3H:1V for ease of mowing and routine maintenance. Flatter slopes are encouraged, where adequate space is available, to enhance pretreatment of sheet flows entering the channel.

Check dams. Check dams may be used for pretreatment, to break up slopes, and to increase the hydraulic residence time in the channel. Design requirements for check dams are as follows:

- Check dams should be spaced based on the channel slope, as needed to increase residence time, provide design storm storage volume, or any additional volume attenuation requirements. In typical spacing, the ponded water at a downhill check dam should not touch the toe of the upstream check dam. More frequent spacing may be desirable in dry swales to increase the ponding volume.
- The maximum desired check dam height is 12 inches, for maintenance purposes. However, for some sites, a maximum of 18 inches can be allowed, with additional design elements to

ensure the stability of the check dam and the adjacent and underlying soils. The average ponding depth throughout the channel should be 12 inches.

- Armoring may be needed at the downstream toe of the check dam to prevent erosion.
- Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the channel bottom so as to prevent hydrostatic head from pushing out the underlying soils.
- Check dams must be designed with a center weir sized to pass the channel design storm peak flow (15-year storm event for man-made channels).
- For grass channels, each check dam must have a weep hole or similar drainage feature so it can dewater after storms. This is not appropriate for dry swales.
- Check dams should be composed of wood, concrete, stone, compacted soil, or other non-erodible material, or should be configured with elevated driveway culverts.
- Individual channel segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.

Check dams for grass channels must be spaced to reduce the effective slope to less than 2 percent, as indicated below in Table 3.35.

Table 3.35 Typical Check Dam Spacing to Achieve Effective Channel Slope

Channel Longitudinal Slope (%)	Check Dam[a, b] Spacing[c] to Achieve Effective Slope (ft)	
	Effective Slope of 2%	Effective Slope of 0%–1%
0.5	–	200–
1.0	–	100–
1.5	–	67–200
2.0	–	50–100
2.5	200	40–67
3.0	100	33–50
3.5	67	30–40
4.0	50	25–33
4.5[d]	40	20–30
5.0[d]	40	20–30

[a] All check dams require a stone energy dissipater at the downstream toe.
[b] Check dams require weep holes at the channel invert. Swales with slopes less than 2 percent will require multiple weep holes (at least 3) in each check dam.
[c] Maximum check dam spacing height is 12 inches. The spacing dimension is half of the above distances if a 6-inch check dam is used.
[d] Open channels with slopes greater than 4 percent require special design considerations, such as drop structures to accommodate greater than 12-inch high check dams (and therefore a flatter effective slope), in order to ensure non-erosive flows.

Ponding Depth. Check dams must be used in dry swales to create ponding cells along the length of the channel. The maximum ponding depth in a dry swale must not exceed 18 inches. Minimum surface ponding depth is 3 inches (averaged over the surface area of the open channel).In order to increase the ponding depth, it may be necessary or desirable to space check dams more frequently than is shown in Table 3.35.

Dry Swale Filter Media. Dry swales require replacement of native soils with a prepared filter media. The soil media provides adequate drainage, supports plant growth, and facilitates pollutant removal within the dry swale. At least 18 inches of filter media must be added above the choker stone layer (and no more than 6 feet) to create an acceptable filter. The recipe for the filter media is identical to that used for bioretention and is provided in Section 3.6 Bioretention. The batch receipt confirming the source of the filter media must be submitted to the DDOE inspector. One acceptable design adaptation is to use 100 percent sand for the first 18 inches of the filter and add a combination of topsoil and compost, as specified in Appendix J, for the top 4 inches, where turf cover will be maintained.

Dry Swale Drawdown. Dry swales must be designed so that the desired design storm volume is completely filtered within 72 hours, using the equations specified in Section 3.9.6.

Dry Swale Underdrain. Some dry swale designs will not use an underdrain (where soil infiltration rates meet minimum standards). See Section 3.9.1 Open Channel Feasibility Criteria for more details. When underdrains are necessary, they should have a minimum diameter of 4 to 6 inches and be encased in a 12-inch deep gravel bed. Two layers of stone should be used. A choker stone layer, consisting of #8 or #78 stone at least 3 inches deep, must be installed immediately below the filter media. Below the choker stone layer, the underdrain must be encased (a minimum of 2 inches above and below the underdrain) in a layer of clean, double washed ASTM D448 No.57 or smaller (No. 68, 8, or 89) stone.

Impermeable Liner. An impermeable liner is not typically required, although it may be utilized in fill applications where deemed necessary by a geotechnical investigation, on sites with contaminated soils, or on the sides of the practice to protect adjacent structures from seepage. Use a 30-mil (minimum) PVC geomembrane liner. (Follow manufacturer’s instructions for installation.) Field seams must be sealed according to the liner manufacturer’s specifications. A minimum 6-inch overlap of material is required at all seams.

Dry Swale Observation Well. A dry swale must include observation wells with cleanout pipes along the length of the swale. The wells should be tied into any Ts or Ys in the underdrain system and must extend upward above the surface of the dry swale.

Grass Channel Material Specifications. The basic material specifications for grass channels are outlined in Table 3.36 below.

Table 3.36 Grass Channel Material Specifications

Component	Specification
Grass	A dense cover of water-tolerant, erosion-resistant grass. The selection of an appropriate species or mixture of species is based on several factors including climate, soil type, topography, and sun or shade tolerance. Grass species should have the following characteristics: ▪ A deep root system to resist scouring; ▪ A high stem density with well-branched top growth; ▪ Water-tolerance; ▪ Resistance to being flattened by runoff; ▪ An ability to recover growth following inundation; and ▪ If receiving runoff from roadways, salt-tolerance.
Check Dams	Check dams should be constructed of a non-erosdible material such as wood, gabions, riprap, or concrete. Wood used for check dams should consist of pressure-treated logs or timbers or water-resistant tree species such as cedar, hemlock, swamp oak, or locust. Computation of check dam material is necessary, based on the surface area and depth used in the design computations.
Diaphragm	Pea gravel used to construct pretreatment diaphragms must consist of washed, open-graded, course aggregate between 3 and 10 mm in diameter.
Erosion Control Fabric	Where flow velocities dictate, biodegradable erosion control netting or mats that are durable enough to last at least two growing seasons must be used, conforming to Standard and Specification 3.36 of the Virginia Erosion and Sediment Control Handbook.

Dry Swale Material Specifications. For additional material specifications pertaining to dry swales, designers should consult Section 3.6.4 and Table 3.37 below.

Table 3.37 Dry Swale Material Specifications

Material	Specification	Notes
Filter Media Composition	Filter Media to contain: ▪ 80-90% sand ▪ 10-20% soil fines ▪ Maximum 10% clay ▪ 3-5% organic matter	To account for settling/compaction, it is recommended that 110% of the plan volume be utilized.
Filter Media Testing	P content = 5 to 15 mg/kg (Mehlich I) or 18 to 40 mg/kg (Mehlich III) CEC > 5 milliequivalents per 100 grams	See Section 3.6 Bioretention, for additional soil media information.
Geotextile	Geotextile fabric meeting the following specifications: ▪ AASHTO M-288 Class 2, latest edition ▪ Has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability ▪ Apply along sides of the filter media only and do not apply along the swale bottom.	

Material	Specification	Notes
Choking Layer	A 2- to 4-inch layer of choker stone (typically #8 or # 89 washed gravel) laid above the underdrain stone.	
Underdrain Stone Layer	Stone must be double-washed and clean and free of all fines (ASTM D448 No. 57 or smaller stone).	
Underdrains, Cleanouts, and Observation Wells	4-inch or 6-inch rigid schedule 40 PVC pipe, with 3/8-inch perforations.	Install perforated pipe for the full length of the Dry Swale cell. Use non-perforated pipe, as needed, to connect with the storm drain system.
Impermeable Liner	Where appropriate, use a thirty mil (minimum) PVC Geomembrane liner	
Vegetation	Plant species as specified on the landscaping plan	
Check Dams	Use non-erosive material, such as wood, gabions, riprap, or concrete. Wood used for check dams should consist of pressure-treated logs or timbers, or water-resistant tree species, such as cedar, hemlock, swamp oak, or locust.	
Erosion Control Fabric	Where flow velocities dictate, use woven biodegradable erosion control fabric or mats (EC2) that are durable enough to last at least 2 growing seasons.	

Wet Swale Design Issues. The following criteria apply to the design of wet swales:

- The average normal pool depth (dry weather) throughout the swale must be 6 inches or less.
- The maximum temporary ponding depth in any single Wet Swale cell must not exceed 18 inches at the most downstream point (e.g., at a check dam or driveway culvert).
- Check dams should be spaced as needed to maintain the effective longitudinal slope.
- Individual Wet Swale segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.
- Wet Swale side slopes should be no steeper than 4H:1V to enable wetland plant growth. Flatter slopes are encouraged where adequate space is available, to enhance pretreatment of sheet flows entering the channel. Under no circumstances are side slopes to steeper than 3H:1V.

Grass Channel Enhancement using Compost Soil Amendments. Soil compost amendments serve to increase the retention capability of a grass channel. The following design criteria apply when compost amendments are used:

- The compost-amended strip must extend over the length and width of the channel bottom, and the compost must be incorporated to a depth as outlined in Appendix J.
- The amended area will need to be rapidly stabilized with perennial, salt tolerant grass species.
- For grass channels on steep slopes, it may be necessary to install a protective biodegradable erosion control mat to protect the compost-amended soils. Care must be taken to consider the erosive characteristics of the amended soils when selecting an appropriate erosion control mat.

Grass Channel Sizing. Unlike other BMPs, grass channels are designed based on a peak rate of flow. Designers must demonstrate channel conveyance and treatment capacity in accordance with the following guidelines:

- Hydraulic capacity should be verified using Manning's Equation or an accepted equivalent method, such as erodibility factors and vegetal retardance.
- The flow depth for the peak flow generated by the SWRv must be maintained at 4 inches or less.
- Manning's "n" value for grass channels is 0.2 for flow depths up to 4 inches, decreasing to 0.03 at a depth of 12 inches and above, which would apply to the 2-year and 15-year storms if an on-line application (Haan et. al, 1994).
- Peak flow rates for the 2-year and 15-year frequency storms must be non-erosive, in accordance with Table 3.38 (see Section 3.9.5 Open Channel Landscaping Criteria), or subject to a site-specific analysis of the channel lining material and vegetation; and the 15-year peak flow rate must be contained within the channel banks (with a minimum of 6 inches of freeboard).
- Calculations for peak flow depth and velocity must reflect any increase in flow along the length of the channel, as appropriate. If a single flow is used, the flow at the outlet must be used.
- The hydraulic residence time (e.g., the average travel time for a particle of water through a waterbody) must be a minimum of 9 minutes for the peak flows from the SWRv or design storm (Mar et al., 1982; Barrett et al., 1998; Washington State Department of Ecology, 2005). If flow enters the swale at several locations, a 9-minute minimum hydraulic residence time must be demonstrated for each entry point, using Equation 3.15 through Equation 3.19 below.

The bottom width of the grass channel is therefore sized to maintain the appropriate flow geometry as follows:

Equation 3.15 Manning's Equation

$$V = \left(\frac{1.49}{n}\right) \times D^{2/3} \times S^{1/2}$$

where:

V	=	flow velocity (ft/s)
n	=	roughness coefficient (0.2, or as appropriate)
D	=	flow depth (ft) (Note: D approximates hydraulic radius for shallow flows)
S	=	channel slope (ft/ft)

Equation 3.16 Continuity Equation

$$Q = V(W \times D)$$

where:

Q	=	design storm peak flow rate (cfs)
V	=	design storm flow velocity (ft/s)
W	=	channel width (ft)
D	=	flow depth (ft)

(Note: Channel width (W) multiplied by depth (D) approximates the cross-sectional flow area for shallow flows.)

Combining Equation 3.15 and Equation 3.16, and re-writing them provides a solution for the minimum width:

Equation 3.17 Minimum Width

$$W = \frac{n \times Q}{1.49 \times D^{5/3} \times S^{1/2}}$$

Solving Equation 3.20 for the corresponding velocity provides:

Equation 3.18 Corresponding Velocity

$$V = \frac{Q}{W \times D}$$

The width, slope, or Manning's "n" value can be adjusted to provide an appropriate channel design for the site conditions. However, if a higher density of grass is used to increase the Manning's "n" value and decrease the resulting channel width, it is important to provide material specifications and construction oversight to ensure that the denser vegetation is actually established. Equation 3.19 can then be used to ensure adequate hydraulic residence time.

Equation 3.19 Grass Channel Length for Hydraulic Residence Time of 9 minutes (540 seconds)

$$L = 540 \times V$$

where:

L	=	minimum swale length (ft)
V	=	flow velocity (ft/s)

The storage volume (Sv) provided by the grass channel is equal to the total runoff from the design storm (typically SWRv) used to size the channel (conveyed at a depth of 4 inches or less).

Equation 3.20 Grass Channel Storage Volume

$$Sv = DesignStorm$$

where:

DesignStorm	=	*SWRv* or other design storm volume (ft^3) (e.g., portion of the *SWRv*)

Dry Swale Sizing. Dry swales are typically sized to capture the SWRv or larger design storm volumes in the surface ponding area, soil media, and gravel reservoir layers of the dry swale.

Total storage volume of the BMP is calculated using Equation 3.21.

Equation 3.21 Dry Swale Storage Volume

$$Sv = SA_{bottom} \times [(d_{media} \times \eta_{media}) + (d_{gravel} \times \eta_{gravel})] + (SA_{average} \times d_{ponding})$$

where:

Sv	=	total storage volume of dry swale (ft^3)
SA_{bottom}	=	bottom surface area of dry swale (ft^2)
d_{media}	=	depth of the filter media (ft)
η_{media}	=	effective porosity of the filter media (typically 0.25)
d_{gravel}	=	depth of the underdrain and underground storage gravel layer(ft)
η_{gravel}	=	effective porosity of the gravel layer (typically 0.4)
$SA_{average}$	=	the average surface area of the dry swale (ft^2) typically, where SA_{top} is the top surface area of bioretention, $SA_{average} = \frac{SA_{bottom} + SA_{top}}{2}$
$d_{ponding}$	=	the maximum ponding depth of the dry swale (ft)

Equation 3.21 can be modified if the storage depths of the soil media, gravel layer, or ponded water vary in the actual design or with the addition of any surface or subsurface storage components (e.g., additional area of surface ponding, subsurface storage chambers, etc.). The maximum depth of ponding in the dry swale must not exceed 18 inches. If storage practices will be provided off-line or in series with the dry swale, the storage practices should be sized using the guidance in Section 3.12 Storage Practices.

Dry swales can be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The *Sv* can be counted as part of the 2-year or 15-year runoff volumes to satisfy stormwater quantity control requirements.

Note: In order to increase the storage volume of a dry swale, the ponding surface area may be increased beyond the filter media surface area. However, the top surface are of the BMP (at the top of the ponding elevation) may not be more than twice the size of surface area of the filter media (SA_{bottom}).

Wet Swale Sizing. Wet swales can be designed to capture and treat the SWRv remaining from any upstream stormwater retention practices. The storage volume is made up of the temporary and permanent storage created within each wet swale cell. This includes the permanent pool volume and up to 12 inches of temporary storage created by check dams or other design features that has 24 hours extended detention.

The storage volume (Sv) of the practice is equal to the volume provided by the pond permanent pool plus the 24-hour extended detention (ED) volume provided by the practice (Equation 3.22). The total Sv cannot exceed the design SWRv.

Equation 3.22 Wet Swale Storage Volume

$$Sv = \text{Pond permanent pool volume} + \text{24-hour ED volume}$$

3.9.5 Open Channel Landscaping Criteria

All open channels must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. There are several types of grasses appropriate for dry open channels (grass channels and dry swales). These are listed in Table 3.38. Designers should choose plant species that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Designers should ensure that the maximum flow velocities do not exceed the values listed in the table for the selected grass species and the specific site slope.

Table 3.38 Recommended Vegetation for Open Channels

Vegetation Type	Slope (%)	Maximum Velocity (ft/s)	
		Erosion Resistant Soil	Easily Eroded Soil
Bermuda Grass	0-5	8	6
	5-10	7	5
	>10	6	4
Kentucky Bluegrass	0-5	7	5
	5-10	6	4
	>10	5	3
Tall Fescue Grass Mixture	0-5	6	4
	5-10	4	3
Annual and Perennial Rye	0-5	4	3
Sod		4	3

Source: USDA, TP-61, 1954; Roanoke Virginia, Stormwater Design Manual, 2008

Wet swales should be planted with grass and wetland plant species that can withstand both wet and dry periods as well as relatively high velocity flows within the channel. For a list of wetland plant species suitable for use in wet swales, refer to the wetland panting guidance and plant lists provided in Section 3.11 Stormwater Wetlands.

If roadway salt will be applied to the contributing drainage area, open channels should be planted with salt-tolerant plant species.

Landscape design shall specify proper grass species based on site-specific soils and hydric conditions present along the channel.

Open channels should be seeded at such a density to achieve a 90 percent vegetated cover after the second growing season. Taller and denser grasses are preferable, although the species is less important than good stabilization and dense vegetative cover.

Grass channels should be seeded and not sodded. Seeding establishes deeper roots and sod may have muck soil that is not conducive to infiltration. Grass channels should be protected by a biodegradable erosion control fabric to provide immediate stabilization of the channel bed and banks.

3.9.6 Open Channel Construction Sequence

Design Notes. Channel invert and tops of banks are to be shown in plan and profile views. A cross sectional view of each configuration must be shown for proposed channels. Completed limits of grading must be shown for proposed channels. For proposed channels, the transition at the entrance and outfall is to be clearly shown on plan and profile views.

Open Channel Installation. The following is a typical construction sequence to properly install open channels, although steps may be modified to reflect different site conditions or design variations. Grass channels should be installed at a time of year that is best to establish turf cover without irrigation. For more specific information on the installation of wet swales, designers should consult the construction criteria outlined in Section 3.11 Stormwater Wetlands.

Step 1: **Protection During Site Construction.** Ideally, open channels should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical, given that the channels are a key part of the drainage system at most sites. In these cases, temporary soil erosion and sediment controls such as dikes, silt fences and other erosion control measures should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, and erosion control fabric should be used to protect the channel. Dry Swales that lack underdrains (and rely on infiltration) must be fully protected by silt fence or construction fencing to prevent compaction by heavy equipment during construction.

Step 2: **Installation.** 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. Soil erosion and sediment controls for construction of the channel must be installed as specified in the soil erosion and sediment control plan. Stormwater flows must not be permitted into the channel until the bottom and side slopes are fully stabilized.

Step 3: **Grading.** Grade the grass channel to the final dimensions shown on the plan. Excavators or backhoes should work from the sides to grade and excavate the open channels to the appropriate design dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the open channel area. If constructing a dry swale, the bottom of the swale should be ripped, rototilled or otherwise scarified to promote greater infiltration.

Step 4: **Placing Stone Layer (for dry swales).** If constructing a dry swale, place an acceptable geotextile fabric on the underground (excavated) sides of the dry swale with a minimum 6 inch overlap. Place the stone needed for storage layer over the filter bed. Perforate the underdrain pipe. Add the remaining stone jacket, and then pack #57 stone (clean double washed) to 3 inches above the top of the underdrain, and then add 3 inches of pea gravel as a filter layer. Add the soil media in 12-inch lifts until the desired top elevation of the dry swale is achieved. Water thoroughly and add additional media as needed where settlement has occurred.

Step 5: **Add Amendments (optional, for grass channels).** Add soil amendments as needed. Till the bottom of the grass channel to a depth of 1 foot and incorporate compost amendments according to Appendix J.

Step 6: **Install Check Dams**. Install check dams, driveway culverts and internal pretreatment features as shown on the plan. Fill material used to construct check dams should be placed in 8- to 12-inch lifts and compacted to prevent settlement. The top of each check dam must be constructed level at the design elevation.

Step 7: **Hydro-seed.** Hydro-seed the bottom and banks of the open channel, and peg in erosion control fabric or blanket where needed. After initial planting, a biodegradable erosion control fabric should be used, conforming to the District of Columbia Soil Erosion and Sediment Control Standards and Specifications.

Step 8: **Plant.** 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 9: **Final Inspection.** A qualified professional should conduct the final construction inspection and develop a punch list for facility acceptance.

Open Channel Construction Supervision. Supervision during construction is recommended to ensure that the open channel is built in accordance with these specifications.

DDOE's construction phase inspection checklist is available in Appendix K.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of dry swale installation:

- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the channel beds and their contributing side-slopes.
- Inspect check dams and pretreatment structures to make sure they are at correct elevations, are properly installed, and are working effectively.
- For dry swale designs:
  - Check the filter media to confirm that it meets specifications and is installed to the correct depth.
  - Check elevations, such as the invert of the underdrain, inverts for the inflow and outflow points, and the ponding depth provided between the surface of the filter bed and the overflow structure.

- Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

The real test of an open channel occurs after its first big storm. The post-storm inspection should focus on whether the desired sheetflow, shallow concentrated flows or fully concentrated flows assumed in the plan actually occur in the field. Minor adjustments are normally needed as part of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets, or realignment of outfalls and check dams). Also, a qualified professional should check that dry swale practices drain completely within the 72-hour drawdown period.

3.9.7 Open Channel Maintenance Criteria

Maintenance is a crucial and required element that ensures the long-term performance of open channels. 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. Dry swale designs may require regular pruning and management of trees and shrubs. The surface of dry swale filter beds 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. Table 3.39 provides a schedule of typical maintenance activities required for open channels.

Table 3.39 Typical Maintenance Activities and Schedule for Open Channels

Schedule	Maintenance Activity
As needed	▪ Mow grass channels and dry swales during the growing season to maintain grass heights in the 4- to 6-inch range.
Quarterly	▪ Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. ▪ Ensure that the contributing drainage area is stabilized. Perform spot-reseeding if where needed. ▪ Remove accumulated sediment and oil/grease from inlets, pretreatment devices, flow diversion structures, and overflow structures. ▪ Repair undercut and eroded areas at inflow and outflow structures.
Annual inspection	▪ Add reinforcement planting to maintain 90% turf cover. Reseed any salt-killed 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 weep holes. ▪ 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.

Maintenance Inspections. Annual inspections by a qualified professional are used to trigger maintenance operations, such as sediment removal, spot revegetation, and inlet stabilization. DDOE's maintenance inspection checklists for disconnection and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.9.8 Open Channel Stormwater Compliance Calculations

Grass Channels receive 10 percent retention value and are not an accepted total suspended solids practice for the amount of storage volume (Sv) provided by the BMP (Table 3.40).

Table 3.40 Grass Channel Retention Value and Pollutant Removal

Retention Value	$= 0.1\times Sv$
Accepted Total Suspended Solids (TSS) Treatment Practice	No

Grass channels on amended soils receive 30 percent retention value l for the amount of storage volume (Sv) provided by the practice (Table 3.41).

Table 3.41 Grass Channel on Amended Soils Retention Value and Pollutant Removal

Retention Value	$= 0.3 \times Sv$
Accepted TSS Treatment Practice	No

Dry swales receive 60 percent retention value and are an accepted TSS removal practice for the amount of storage volume (Sv) provided by the practice (Table 3.42).

Table 3.42 Dry Swale Retention Value and Pollutant Removal

Retention Value	= 0.6 × *Sv*
Accepted TSS Treatment Practice	Yes

Wet swales receive 10 percent retention value and are an accepted TSS removal practice for the amount of storage volume (Sv) provided by the BMP (Table 3.43).

Table 3.43 Wet Swale Retention Value and Pollutant Removal

Retention Value	= 0.1 × *Sv*
Accepted TSS Treatment Practice	Yes

All practices must be sized using the guidance detailed in Section 3.9.4. Open Channel Design Criteria.

Grass channels and dry swales also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the Sv or Retention Value from the total runoff volume for the 2-year, 15-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a Reduced Natural Resource Conservation Service (NRCS) Curve Number for the site or drainage area. The Reduced Curve Number can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

3.9.9 References

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3.10 Ponds

Definition. Stormwater ponds are stormwater storage practices that consist of a combination of a permanent pool, micropool, or shallow marsh that promote a good environment for gravitational settling, biological uptake and microbial activity. Ponds are widely applicable for most land uses and are best suited for larger drainage areas. Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants deposited during prior storms. When sized properly, stormwater ponds have a residence time that ranges from many days to several weeks, which allows numerous pollutant removal mechanisms to operate. Stormwater ponds can also provide storage above the permanent pool to help meet stormwater management requirements for larger storms. Design variants include:

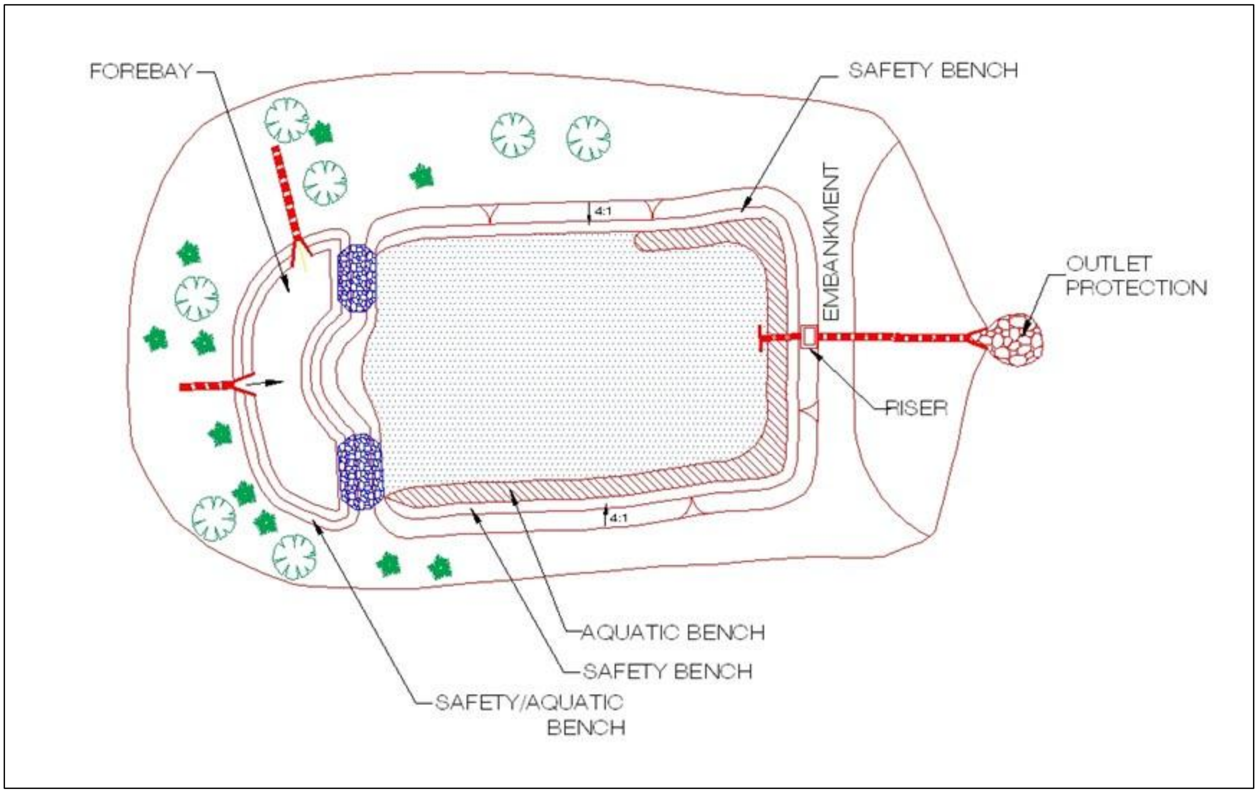
P-1 Micropool extended detention pond

P-2 Wet pond

P-3 Wet extended detention pond

Stormwater ponds should be considered for use after all other upland retention opportunities have been exhausted and there is still a remaining treatment volume or runoff from larger storms (i.e., 2-year, 15-year or flood control events) to manage.

Stormwater ponds do not receive any stormwater retention value and should be considered only for management of larger storm events. Stormwater ponds have both community and environmental concerns (see Section 3.10.1 Pond Feasibility Criteria) that should be considered before choosing stormwater ponds for the appropriate stormwater practice on site.



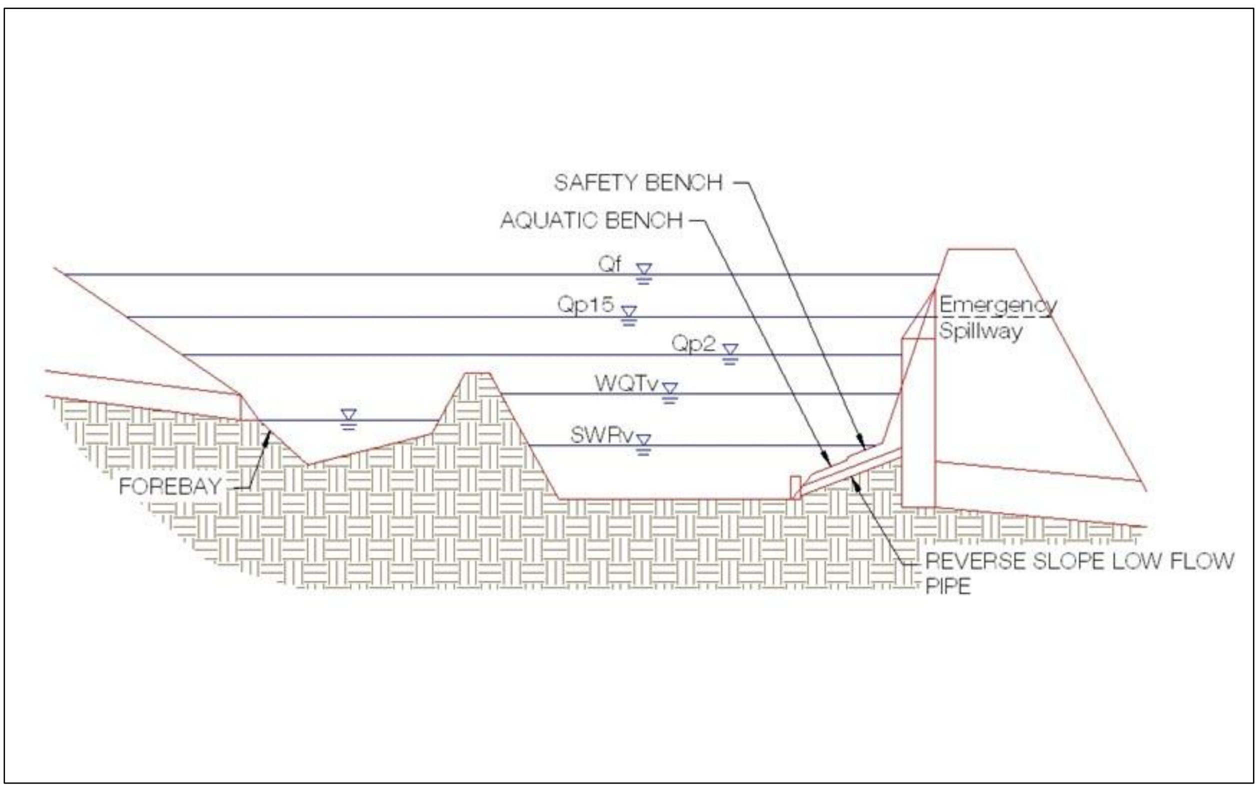
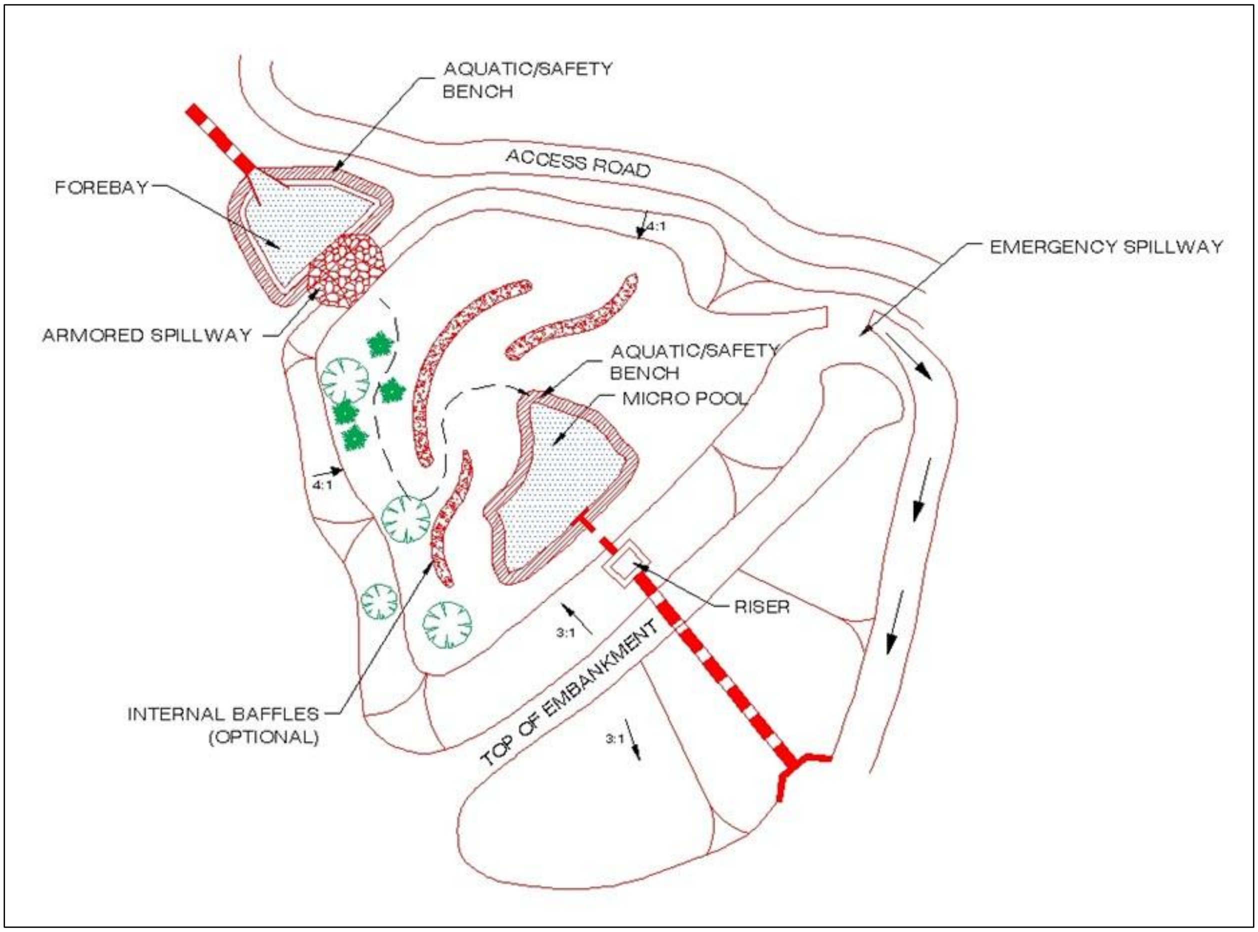


Figure 3.35 Design schematics for a wet pond (P-2).



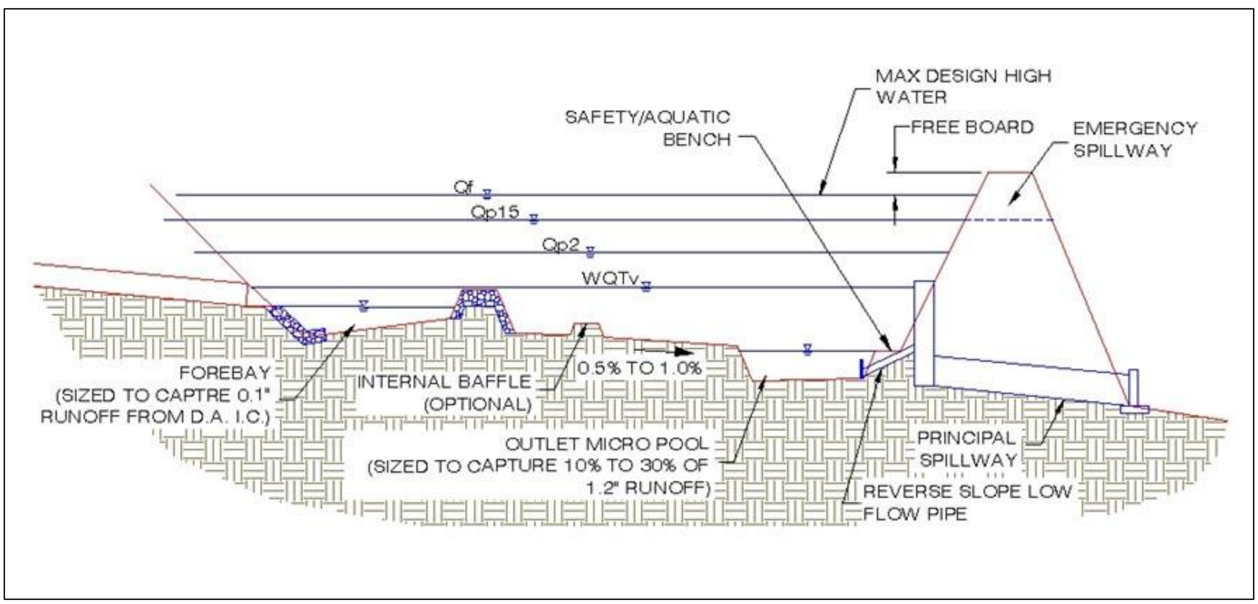


Figure 3.36 Typical extended detention pond (P-3) details.

3.10.1 Pond Feasibility Criteria

The following feasibility issues need to be considered when ponds are considered a final stormwater management practice of the treatment train.

Adequate Water Balance. Wet ponds must have enough water supplied from groundwater, runoff or baseflow so that the wet pools will not draw down by more than 2 feet after a 30-day summer drought. A simple water balance calculation must be performed using the equation provided in Section 3.10.4. Wetland Design Criteria and Section 3.11.4 Wetland Design Criteria.

Contributing Drainage Area. A contributing drainage area of 10 to 25 acres is typically recommended for ponds to maintain constant water elevations. Ponds can still function with drainage areas less than 10 acres, but designers should be aware that these “pocket” ponds will be prone to clogging, experience fluctuating water levels, and generate more nuisance conditions.

Space Requirements. The surface area of a pond will normally be at least 1 to 3 percent of its contributing drainage area, depending on the pond’s depth.

Site Topography. Ponds are best applied when the grade of contributing slopes is less than 15 percent.

Available Hydraulic Head. The depth of a pond is usually determined by the hydraulic head available on the site. The bottom elevation is normally the invert of the existing downstream conveyance system to which the pond discharges. Typically, a minimum of 6 to 8 feet of head are needed to hold the wet pool and any additional large storm storage or overflow capacity for a pond to function.

Setbacks. To avoid the risk of seepage, stormwater ponds must not be hydraulically connected to structure foundations. Setbacks to structures must be at least 10 feet and adequate water-proofing protection must be provided for foundations and basements.

Proximity to Utilities. For an open pond system, no utility lines shall be permitted to cross any part of the embankment of a wet pool.

Depth to Water Table. The depth to the groundwater table is not a major constraint for wetponds because a high water table can help maintain wetland conditions. However, groundwater inputs can also reduce the pollutant removal rates of ponds. Further, if the water table is close to the surface, it may make excavation difficult and expensive.

Soils. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Soil infiltration tests need to be conducted at proposed pond sites to determine the need for a pond liner or other method to ensure a constant water surface elevation. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most HSG A soils and some HSG B soils will require a liner (see Table 3.44). Geotechnical tests should be conducted to determine the infiltration rates and other subsurface properties of the soils beneath the proposed pond.

Use of or Discharges to Natural Wetlands. Ponds cannot be located within jurisdictional waters, including wetlands, without obtaining a section 404 permit from the appropriate state or federal regulatory agency. In addition, the designer should investigate the wetland status of adjacent areas to determine if the discharge from the pond will change the hydroperiod of a downstream natural wetland (see Cappiella et al., 2006, for guidance on minimizing stormwater discharges to existing wetlands).

Perennial Streams. Locating ponds on perennial streams will require both a Section 401 and Section 404 permit from the appropriate state or federal regulatory agency.

Community and Environmental Concerns. Ponds can generate the following community and environmental concerns that need to be addressed during design:

- Aesthetic Issues. Many residents feel that ponds are an attractive landscape feature, promote a greater sense of community and are an attractive habitat for fish and wildlife. Designers should note that these benefits are often diminished where ponds are under-sized or have small contributing drainage areas.
- Existing Forests. Construction of a pond may involve extensive clearing of existing forest cover. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during pond design and construction. In the District of Columbia a permit is required to remove a tree with a circumference greater than 55-inches on private lands. A permit is required to prune or remove any street tree between the sidewalk and the curb. These permits are issued by the District Department of Transportation, Urban Forestry Administration (UFA).
- Safety Risk. Pond safety is an important community concern, since both young children and adults have perished by drowning in ponds through a variety of accidents, including falling through thin ice cover. Gentle side slopes and safety benches should be provided to avoid potentially dangerous drop-offs, especially where ponds are located near residential areas.
- Pollutant Concerns. Ponds collect and store water and sediment to increase residence time that will increase the likelihood for contaminated water and sediments to be neutralized. However, poorly sized, maintained, and/or functioning ponds can export contaminated sediments and/or water to receiving waterbodies (Mallin, 2000; Mallin et al., 2001; Messersmith, 2007). Further, designers are cautioned that recent research on ponds has shown that some ponds can be hotspots or incubators for algae that generate harmful algal blooms (HABs).
- Mosquito Risk. Mosquitoes are not a major problem for larger ponds (Santana et al., 1994; Ladd and Frankenburg, 2003, Hunt et al, 2005). However, fluctuating water levels in smaller or under-sized ponds could pose some risk for mosquito breeding. Mosquito problems can be minimized through simple design features and maintenance operations described in MSSC (2005).
- Geese and Waterfowl. Ponds with extensive turf and shallow shorelines can attract nuisance populations of resident geese and other waterfowl, whose droppings add to the nutrient and bacteria loads, thus reducing the removal efficiency for those pollutants. Several design and landscaping features can make ponds much less attractive to geese (see Schueler, 1992).

3.10.2 Pond Conveyance Criteria

Internal Slope. The longitudinal slope of the pond bottom should be at least 0.5 to 1 percent to facilitate maintenance.

Primary Spillway. The spillway shall be designed with acceptable anti-flotation, anti-vortex and trash rack devices. The spillway must generally be accessible from dry land. When reinforced concrete pipe is used for the principal spillway to increase its longevity, "O-ring" gaskets (ASTM C361) shall be used to create watertight joints.

Non-Clogging Low-Flow Orifice. A low-flow orifice must be provided that is adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection that may allow for smaller diameters. Orifices less than 3 inches in diameter may require extra attention during design, to minimize the potential for clogging.

- One option is a submerged reverse-slope pipe that extends downward from the riser to an inflow point 1 foot below the normal pool elevation.
- Alternative methods must employ a broad crested rectangular V-notch (or proportional) weir, protected by a half-round CMP that extends at least 12 inches below the normal pool elevation.

Emergency Spillway. Ponds must be constructed with overflow capacity to pass the 100-year design storm event through either the primary spillway or a vegetated or armored emergency spillway unless waived by DDOE.

Adequate Outfall Protection. The design must specify an outfall that will be stable for the 15-year design storm event. The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance. This is typically done by placing appropriately sized riprap over geotextile fabric, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps) depending on the channel lining material. Flared pipe sections, which discharge at or near the stream invert or into a step pool arrangement, should be used at the spillway outlet.

When the discharge is to a manmade pipe or channel system, the system must be adequate to convey the required design storm peak discharge.

If a pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of rip-rap should be avoided.

The final release rate of the facility shall be modified if any increase in flooding or stream channel erosion would result at a downstream structure, highway, or natural point of restricted streamflow (see Section 2.6 Additional Stormwater Management Requirements).

Inlet Protection. Inflow points into the pond must be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (i.e., the 15-year storm event). Inlet pipe inverts should generally be located at or slightly below the permanent pool elevation. A forebay shall be provided at each inflow location, unless the inlet is submerged or inflow provides less than 10 percent of the total design storm inflow to the pond.

Dam Safety Permits. The designer must verify whether or not Dam Safety permits or approvals are required for the embankment.

3.10.3 Pond Pretreatment Criteria

Sediment forebays are considered to be an integral design feature to maintain the longevity of all ponds. A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. The following criteria apply to forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel serving at least 10 percent of the pond's contributing drainage area.
- The forebay consists of a separate cell, formed by an acceptable barrier (e.g., an earthen berm, concrete weir, gabion baskets, etc.).
- The forebay should be between 4 and 6 feet deep and must be equipped with a variable width aquatic bench for safety purposes. The aquatic bench should be 4 to 6 feet wide at a depth of 1 to 2 feet below the water surface. Small forebays may require alternate geometry to achieve the goals of pretreatment and safety within a small area.
- The forebay shall be sized to contain 0.1 inches of runoff from the contributing drainage impervious area. The relative size of individual forebays should be proportional to the percentage of the total inflow to the pond.
- The bottom of the forebay may be hardened (e.g., with concrete, asphalt, or grouted riprap) to make sediment removal easier.
- The forebay must be equipped with a metered rod in the center of the pool (as measured lengthwise along the low-flow water travel path) for long-term monitoring of sediment accumulation.
- Exit velocities from the forebay shall be non-erosive or an armored overflow shall be provided. Non-erosive velocities are 4 feet per second for the two-year event, and 6 feet per second for the 15-year event.
- Direct maintenance access for appropriate equipment shall be provided to the each forebay.
- The bottom of the forebay may be hardened to make sediment removal easier.

3.10.4 Pond Design Criteria

Pond Storage Design. The pond permanent pool must be sized to store a volume equivalent to the SWRv. Volume storage may be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flowpaths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, ED, and marsh).

Pond Geometry. Pond designs should have an irregular shape and a long flow path from inlet to outlet, to increase water residence time and pond performance. The minimum length to width ratio (i.e., length relative to width) for ponds is 1.5:1. Greater flowpaths and irregular shapes are recommended. Internal berms, baffles, or vegetated peninsulas can be used to extend flow paths and/or create multiple pond cells.

Permanent Pool Depth. The maximum depth of the permanent pool should not generally exceed eight feet unless the pond is designed for multiple uses.

Micropool. A micropool is a three to six foot deep pool used to protect the low-flow pipe from clogging and to prevent sediment resuspension. For micropool extended detention ponds, the micropool shall be designed to hold at least 10 to 25 percent of the 1.2-inch storm event.

Side Slopes. Side slopes for ponds should generally have a gradient no steeper than 3H:1V. Mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance.

Maximum Extended Detention Levels. The total storage, including any ponding for larger flooding events (100-year storm) should not extend more than 5 feet above the pond permanent pool unless specific design enhancements to ensure side slope stability, safety, and maintenance are identified and approved.

Stormwater Pond Benches. The perimeter of all pool areas greater than 4 feet in depth must be surrounded by two benches, as follows:

- **Safety Bench.** This is a flat bench located just outside of the perimeter of the permanent pool to allow for maintenance access and reduce safety risks. Except when the stormwater pond side slopes are 5H:1V or flatter, provide a safety bench that generally extends 8 to 15 feet outward from the normal water edge to the toe of the stormwater pond side slope The maximum slope of the safety bench is 5 percent.
- **Aquatic Bench.** This is a shallow area just inside the perimeter of the normal pool that promotes growth of aquatic and wetland plants. The bench also serves as a safety feature, reduces shoreline erosion, and conceals floatable trash. Incorporate an aquatic bench that generally extends up to 10 feet inward from the normal shoreline, has an irregular configuration, and extends a maximum depth of 18 inches below the normal pool water surface elevation.

Liners. When a stormwater pond is located over highly permeable soils or fractured bedrock, a liner may be needed to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner, acceptable options include the following: (1) a clay liner following the specifications outlined in Table 3.44 below; (2) a 30 mil poly-liner; (3) bentonite; (4) use of chemical additives; or (5) an engineering design, as approved on a case-by-case basis by DDOE. A clay liner must have a minimum thickness of 12 inches with an additional 12 inch layer of compacted soil above it, and it must meet the specifications outlined in Table 3.44. Other synthetic liners can be used if the designer can supply supporting documentation that the material will achieve the required performance.

Table 3.44 Clay Liner Specifications

Property	Test Method	Unit	Specification
Permeability	ASTM D-2434	cm/s	1×10^{-6}
Plasticity Index of Clay	ASTM D-423/424	%	Not less than 15
Liquid Limit of Clay	ASTM D-2216	%	Not less than 30
Clay Particles Passing	ASTM D-422	%	Not less than 30
Clay Compaction	ASTM D-2216	%	95% of standard proctor density

Source: DCR (1999). VA

Required Geotechnical Testing. Soil borings must be taken below the proposed embankment, in the vicinity of the proposed outlet area, and in at least two locations within the proposed pond treatment area. Soil boring data is needed to (1) determine the physical characteristics of the excavated material, (2) determine its adequacy for use as structural fill or spoil, (3) provide data for structural designs of the outlet works (e.g., bearing capacity and buoyancy), (4) determine compaction/composition needs for the embankment (5) determine the depth to groundwater and bedrock and (6) evaluate potential infiltration losses (and the potential need for a liner).

Non-clogging Low-Flow (Extended Detention) Orifice. The low-flow ED orifice shall be adequately protected from clogging by an acceptable external trash rack. The preferred method is a submerged reverse-slope pipe that extends downward from the riser to an inflow point one foot below the normal pool elevation. Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round CMP that extends at least 12 inches below the normal pool.

Riser in Embankment. The riser should be located within the embankment for maintenance access, safety, and aesthetics. Access to the riser is to be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls. The principal spillway opening can be "fenced" with pipe or rebar at 8-inch intervals for safety purposes.

Trash Racks. Trash racks shall be provided for low-flow pipes and for riser openings not having anti-vortex devices.

Pond Drain. Ponds should have a drainpipe that can completely or partially drain the permanent pool. In cases where a low level drain is not feasible (such as in an excavated pond), a pump well must be provided to accommodate a temporary pump intake when needed to drain the pond.

- The drainpipe must have an upturned elbow or protected intake within the pond to help keep it clear of sediment deposition, and a diameter capable of draining the pond within 24 hours.
- The pond drain must be equipped with an adjustable valve located within the riser, where it will not be normally inundated and can be operated in a safe manner.

Care must be exercised during pond drawdowns to prevent downstream discharge of sediments or anoxic water and rapid drawdown. The approving authority shall be notified before draining a pond.

Adjustable Gate Valve. Both the outlet pipe and the pond drain must be equipped with an adjustable gate valve (typically a handwheel activated knife gate valve) or pump well and be sized one pipe size greater than the calculated design diameter. Valves must be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner. To prevent vandalism, the handwheel should be chained to a ringbolt, manhole step, or other fixed object.

Safety Features.

- The principal spillway opening must be designed and constructed to prevent access by small children.
- End walls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a hazard.
- Storage practices must incorporate an additional 1 foot of freeboard above the emergency spillway, or 2 feet of freeboard if design has no emergency spillway, for the maximum Q_f design storm unless more stringent Dam Safety requirements apply.
- The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- Both the safety bench and the aquatic bench should be landscaped with vegetation that hinders or prevents access to the pool.
- Warning signs prohibiting swimming must be posted.
- Where permitted, fencing of the perimeter of ponds is discouraged. The preferred method to reduce risk is to manage the contours of the stormwater pond to eliminate drop-offs or other safety hazards. Fencing is required at or above the maximum water surface elevation in the rare situations when the pond slope is a vertical wall.
- Side slopes to the pond shall not be steeper than 3H:1V, and shall terminate on a 15 ft wide safety bench. Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool. The bench requirement may be waived if slopes are 4H:1V or flatter.

Maintenance Reduction Features. Many maintenance issues can be addressed through well design access. All ponds must be designed for annual maintenance. Good access is needed so crews can remove sediments, make repairs, and preserve pond-treatment capacity. Design for the following,

- ♦ Adequate maintenance access must extend to the forebay, safety bench, riser, and outlet structure and must have sufficient area to allow vehicles to turn around.
- ♦ The riser should be located within the embankment for maintenance access, safety and aesthetics. Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.
- ♦ Access roads must (1) be constructed of load-bearing materials or be built to withstand the expected frequency of use, (2) have a minimum width of 15 feet, and (3) have a profile grade that does not exceed 5:1.

- A maintenance right-of-way or easement must extend to the stormwater pond from a public or private road.

- **Material Specifications.** ED ponds are generally constructed with materials obtained on-site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and geotextile fabric for lining banks or berms.

- **Pond Sizing.** Stormwater ponds can be designed to capture and treat the remaining stormwater discharged from upstream practices from the design storm (SWRv). Additionally, stormwater ponds may be sized to control peak flow rates from the 2-year and 15-year frequency storm event or other design storms as required. Design calculations must ensure that the post-development peak discharge does not exceed the predevelopment peak discharge. See Section 2.7 Hydrology Methods for a summary of acceptable hydrological methodologies and models.

  For treatment train designs where upland practices are utilized for treatment of the SWRv, designers can use a site-adjusted Rv or CN that reflects the volume reduction of upland practices to compute the Qp_2 and Qp_{15} that must be treated by the stormwater pond.

  The pond permanent pool must be sized to store a volume equivalent to the SWRv or design volume.

  The storage volume (Sv) of the practice is equal to the volume provided by the pond permanent pool (Equation 3.23). The total Sv cannot exceed the design SWRv.

Equation 3.23 Pond Storage Volume

$$Sv = \text{Pond permanent pool volume}$$

- **Water Balance Testing.** A water balance calculation is recommended to document that sufficient inflows to wet ponds and wet ED ponds exist to compensate for combined infiltration and evapotranspiration losses during a 30-day summer drought without creating unacceptable drawdowns (see Equation 3.24, adapted from Hunt et al., 2007). The recommended minimum pool depth to avoid nuisance conditions may vary; however, it is generally recommended that the water balance maintain a minimum 24-inch reservoir.

Equation 3.24 Water Balance Equation for Acceptable Water Depth in a Wet Pond

$$DP > ET + INF + RES - MB$$

where:

DP	=	average design depth of the permanent pool (in.)
ET	=	summer evapotranspiration rate (in.) (assume 8 in.)
INF	=	monthly infiltration loss (assume 7.2 at 0.01 in./hour)
RES	=	reservoir of water for a factor of safety (assume 24 in.)
MB	=	measured baseflow rate to the pond, if any convert to pond-inches (in.)

Design factors that will alter this equation are the measurements of seasonal base flow and infiltration rate. The use of a liner could eliminate or greatly reduce the influence of infiltration. Similarly, land use changes in the upstream watershed could alter the base flow conditions over time (e.g., urbanization and increased impervious cover).

Translating the baseflow to inches refers to the depth within the pond. Therefore, Equation 3.25 can be used to convert the baseflow, measured in cubic feet per second (cfs), to pond-inches:

Equation 3.25 Baseflow Conversion

$$Pond - inches = \frac{MB \times 2.592 \times 10^6 \times 12}{SA}$$

where:

pond-inches	=	depth within the pond (in,)
MB	=	measured baseflow rate to the pond (cfs)
2.592 × 106	=	conversion factor from cfs to ft^3/month
12	=	conversion from feet to inches
SA	=	surface area of pond (ft^2)

3.10.5 Pond Landscaping Criteria

Pond Benches. The perimeter of all deep pool areas (four feet or greater in depth) must be surrounded by two benches:

- A safety bench that extends 8 to 15 feet outward from the normal water edge to the toe of the pond side slope. The maximum slope of the safety bench shall be 6 percent.
- An aquatic bench that extends up to 10 feet inward from the normal shoreline and has a maximum depth of 18 inches below the normal pool water surface elevation.

Landscaping and Planting Plan. A landscaping plan must be provided that indicates the methods used to establish and maintain vegetative coverage in the pond and its buffer (see Section 3.6.5 Bioretention Landscaping Criteria for extended landscaping and planting details). Minimum elements of a landscaping plan include the following:

- Delineation of pondscaping zones within both the pond and buffer
- Selection of corresponding plant species
- The planting plan
- The sequence for preparing the wetland benches (including soil amendments, if needed)
- Sources of native plant material
- The landscaping plan should provide elements that promote diverse wildlife and waterfowl use within the stormwater wetland and buffers.
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.
- A vegetated buffer should be provided that extends at least 25 feet outward from the maximum water surface elevation of the pond. Permanent structures (e.g., buildings) should not be constructed within the buffer area. Existing trees should be preserved in the buffer area during construction.
- The soils in the stormwater buffer area are often severely compacted during the construction process, to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration and, therefore, may lead to premature mortality or loss of vigor. As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the root ball for ball-and-burlap stock, and five times deeper and wider for container-grown stock.
- Avoid species that require full shade, or are prone to wind damage. Extra mulching around the base of trees and shrubs is strongly recommended as a means of conserving moisture and suppressing weeds.

For more guidance on planting trees and shrubs in pond buffers, consult Cappiella et al (2006).

3.10.6 Pond Construction Sequence

The following is a typical construction sequence to properly install a stormwater pond. The steps may be modified to reflect different pond designs, site conditions, and the size, complexity and configuration of the proposed facility.

Step 1: **Use of Ponds for Soil Erosion and Sediment Control.** A pond may serve as a sediment basin during project construction. If this is done, the volume should be based on the more stringent sizing rule (soil erosion and sediment control requirement vs. storage volume requirement). Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction pond in mind. The bottom elevation of the pond should be lower than the bottom elevation of the temporary sediment basin. Appropriate procedures must be implemented to prevent discharge of turbid waters when the basin is being converted into a pond.

Approval from DDOE must be obtained before any sediment pond can be used as for stormwater management.

Step 2: **Stabilize the Drainage Area.** Ponds should only be constructed after the contributing drainage area to the pond is completely stabilized. If the proposed pond site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 3: **Assemble Construction Materials On Site**. Inspect construction materials to insure they conform to design specifications, and prepare any staging areas.

Step 4: **Clear and Strip. Bring** the project area to the desired sub-grade.

Step 5: **Soil Erosion and Sediment Controls.** Install soil erosion and sediment control measures prior to construction, including temporary de-watering devices and stormwater diversion practices. All areas surrounding the pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

Step 6: **Excavate the Core Trench and Install the Spillway Pipe**.

Step 7: **Install the Riser or Outflow Structure.** Once riser and outflow structures are installed ensure the top invert of the overflow weir is constructed level at the design elevation.

Step 8: **Construct the Embankment and any Internal Berms.** These features must be installed in 8- to 12-inch lifts, compact the lifts with appropriate equipment.

Step 9: **Excavate and Grade.** Survey to achieve the appropriate elevation and designed contours for the bottom and side slopes of the pond.

Step 10: **Construct the Emergency Spillway.** The emergency spillway must be constructed in cut or structurally stabilized soils.

Step 11: **Install Outlet Pipes**. The installation of outlet pipes must include a downstream rip-rap protection apron.

Step 12: **Stabilize Exposed Soils.** Use temporary seed mixtures appropriate for the pond buffer to stabilize the exposed soils. All areas above the normal pool elevation must be permanently stabilized by hydroseeding or seeding over straw.

Step 13: **Plant the Pond Buffer Area.** Establish the planting areas according to the pondscaping plan (see Section 3.10.5 Pond Landscaping Criteria).

Construction Supervision. Supervision during construction is recommended to ensure that stormwater ponds are properly constructed, especially during the following stages of construction:

- Preconstruction meeting
- Initial site preparation including the installation of soil erosion and sediment control measures
- Excavation/Grading (interim and final elevations)
- Installation of the embankment, the riser/primary spillway, and the outlet structure
- Implementation of the pondscaping plan and vegetative stabilization

- Final inspection (develop a punch list for facility acceptance)

DDOE's construction phase inspection checklist for ponds can be found in Appendix K.

To facilitate maintenance, contractors should measure the actual constructed pond depth at three areas within the permanent pool (forebay, mid-pond and at the riser), and they should mark and geo-reference them on an as-built drawing. This simple data set will enable maintenance inspectors to determine pond sediment deposition rates in order to schedule sediment cleanouts.

3.10.7 Pond Maintenance Criteria

Maintenance is needed so stormwater ponds continue to operate as designed on a long-term basis. Ponds normally have fewer routine maintenance requirements than other stormwater control measures. Stormwater pond maintenance activities vary regarding the level of effort and expertise required to perform them. Routine stormwater pond maintenance, such as mowing and removing debris and trash, is needed several times each year (see Table 3.45). More significant maintenance (e.g., removing accumulated sediment) is needed less frequently but requires more skilled labor and special equipment. Inspection and repair of critical structural features (e.g., embankments and risers) needs to be performed by a qualified professional (e.g., a structural engineer) who has experience in the construction, inspection, and repair of these features.

Sediment removal in the pond pretreatment forebay should occur every 5 to 7 years or after 50 percent of total forebay capacity has been lost. The designer should also check to see whether removed sediments can be spoiled on site or must be hauled away. Sediments excavated from ponds are not usually considered toxic or hazardous. They can be safely disposed of by either land application or land filling. Sediment testing may be needed prior to sediment disposal if the pond serves a hotspot land use.

Table 3.45 Pond Maintenance Tasks and Frequency

Frequency	Maintenance Items
During establishment, as needed (first year)	▪ Inspect the site at least twice after storm events that exceed a 1/2-inch of rainfall. ▪ Plant the aquatic benches with emergent wetland species, following the planting recommendations contained in Section 3.11.6 Wetland Landscaping Criteria. ▪ Stabilize any bare or eroding areas in the contributing drainage area or around the pond buffer ▪ Water trees and shrubs planted in the pond buffer during the first growing season. In general, consider watering every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.
Quarterly or after major storms (>1 inch of rainfall)	▪ Mowing – twice a year ▪ Remove debris and blockages ▪ Repair undercut, eroded, and bare soil areas
Twice a year	▪ Mowing of the buffer and pond embankment
Annually	▪ Shoreline cleanup to remove trash, debris and floatables ▪ A full maintenance inspection ▪ Open up the riser to access and test the valves ▪ Repair broken mechanical components, if needed
Once–during the second year following construction	▪ Pond buffer and aquatic bench reinforcement plantings
Every 5 to 7 years	▪ Forebay Sediment Removal
From 5 to 25 years	▪ Repair pipes, the riser and spillway, as needed

Maintenance Plans. Maintenance plans must clearly outline how vegetation in the pond and its buffer will be managed or harvested in the future. Periodic mowing of the stormwater buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest. The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables.

Maintenance Inspections. Maintenance of a pond is driven by annual inspections by a qualified professional that evaluate the condition and performance of the pond. Based on inspection results, specific maintenance tasks will be triggered.

DDOE's maintenance inspection checklist for stormwater ponds and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.10.8 Pond Stormwater Compliance Calculations

Stormwater ponds receive 10 percent retention value and are an accepted total suspended solids (TSS) treatment practice for the amount of storage volume (Sv) provided by the BMP (Table 3.46).

Table 3.46 Pond Retention Value and Pollutant Removal

Retention Value	$= 0.1 \times Sv$
Accepted TSS Treatment Practice	Yes

3.10.9 References

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Virginia DCR Stormwater Design Specification No. 14: Wet Ponds Version 1.8. 2010.

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3.11 Wetlands

Definition. Practices that create shallow marsh areas to treat urban stormwater which often incorporate small permanent pools and/or extended detention storage. Stormwater wetlands are explicitly designed to provide stormwater detention for larger storms (2-year, 15-year or flood control events) above the design storm (Stormwater Retention Volume (SWRv)) storage. Design variants include:

W-1 Shallow wetland

W-2 Extended detention shallow wetland

Stormwater wetlands, sometimes called constructed wetlands, are shallow depressions that receive stormwater inputs for water quality treatment. Wetlands are typically less than 1 foot deep (although they have greater depths at the forebay and in micropools) and possess variable microtopography to promote dense and diverse wetland cover. Runoff from each new storm displaces runoff from previous storms, and the long residence time allows multiple pollutant removal processes to operate. The wetland environment provides an ideal environment for gravitational settling, biological uptake, and microbial activity.

Stormwater wetlands should be considered for use after all other upland retention opportunities have been exhausted and there is still a remaining treatment volume or runoff from larger storms (i.e., 2-year, 15-year or flood control events) to manage.

Stormwater wetlands do not receive any stormwater retention value and should be considered only for management of larger storm events. Stormwater wetlands have both community and environmental concerns (see Section 3.10.1 Pond Feasibility Criteria) that should be considered before choosing stormwater ponds for the appropriate stormwater practice on site.

Note: All of the pond performance criteria presented in Section 3.10 also apply to the design of stormwater wetlands. Additional criteria that govern the geometry and establishment of created wetlands are presented in this section.

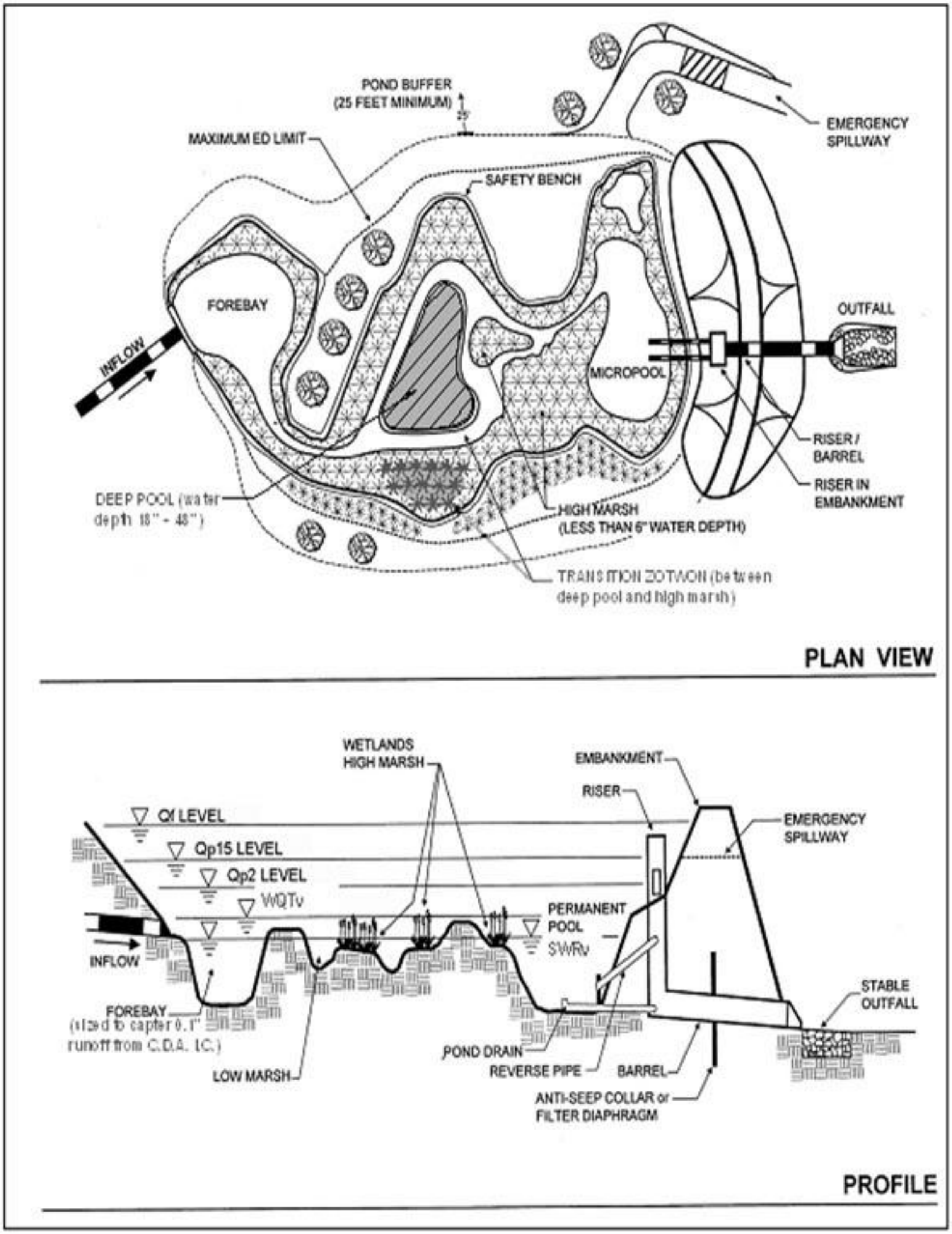


Figure 3.37 Example of extended detention shallow wetland.

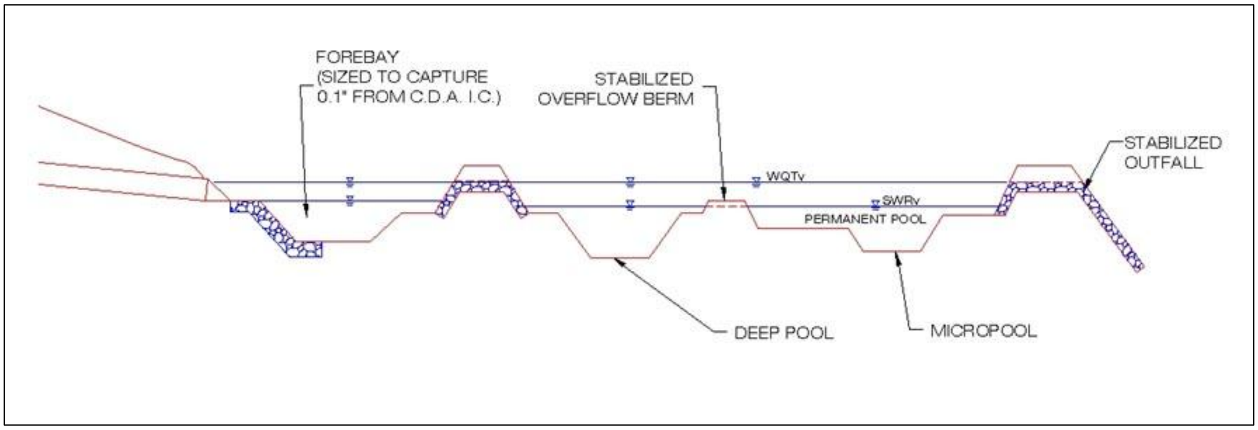


Figure 3.38 Cross section of a typical stormwater wetland.

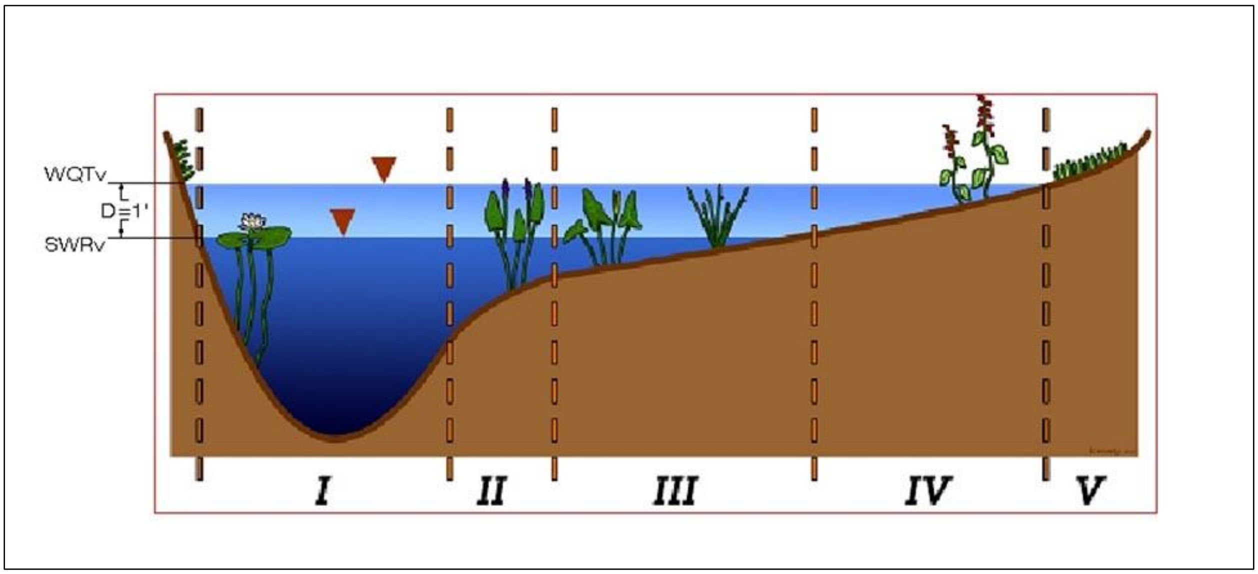


Figure 3.39 Interior wetland zones: (I) Deep Pool (depth -48 to -18 inches), (II) Transition Zone (depth -18 to -6 inches), (III and IV) High Marsh Zone (depth -6 to +6 inches), (IV) Temporary Inundation Area, and (V) Upper Bank (adapted from Hunt et al, 2007).

3.11.1 Wetland Feasibility Criteria

Constructed wetland designs are subject to the following site constraints:

Adequate Water Balance. Wetlands must have enough water supplied from groundwater, runoff or baseflow so that the permanent pools will not draw down by more than 2 feet after a 30-day summer drought. A simple water balance calculation must be performed using the equation provided in Section 3.11.4. Wetland Design Criteria.

Contributing Drainage Area (CDA). The contributing drainage area must be large enough to sustain a permanent water level within the stormwater wetland. If the only source of wetland hydrology is stormwater runoff, then several dozen acres of drainage area are typically needed to maintain constant water elevations. Smaller drainage areas are acceptable if the bottom of the wetland intercepts the groundwater table or if the designer or approving agency is willing to accept periodic wetland drawdown.

Space Requirements. Constructed wetlands normally require a footprint that takes up about 3 percent of the contributing drainage area, depending on the average depth of the wetland and the extent of its deep pool features.

Site Topography. Wetlands are best applied when the grade of contributing slopes is less than 8 percent.

Steep Slopes. A modification of the constructed wetland (and linear wetland or wet swale system) is the regenerative stormwater conveyance (RSC) or step pool storm conveyance channel. The RSC can be used to bring stormwater down steeper grades through a series of step pools. This can serve to bring stormwater down outfalls where steep drops on the edge of the tidal receiving system can create design challenges. For more information on RSC systems, designers can consult the Anne Arundel County Design Specifications, available at http://www.aacounty.org/DPW/Watershed/StepPoolStormConveyance.cfm.

Available Hydraulic Head. The depth of a constructed wetland is usually constrained by the hydraulic head available on the site. The bottom elevation is fixed by the elevation of the existing downstream conveyance system to which the wetland will ultimately discharge. Because constructed wetlands are typically shallow, the amount of head needed (usually a minimum of 2 to 4 feet) is typically less than for wet ponds.

Setbacks. To avoid the risk of seepage, stormwater wetlands must not be hydraulically connected to structure foundations. Setbacks to structures must be at least 10 feet and adequate water-proofing protection must be provided for foundations and basements.

Depth to Water Table. The depth to the groundwater table is not a major constraint for constructed wetlands, since a high water table can help maintain wetland conditions. However, designers should keep in mind that high groundwater inputs may increase excavation costs (refer to Section 3.10 Stormwater Ponds).

Soils. Soil tests should be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed wetland. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most HSG A soils and some HSG B soils will require a liner (see Table 3.44).

Use of or Discharges to Natural Wetlands. Constructed wetlands may not be located within jurisdictional waters, including wetlands, without obtaining a Section 404 permit from the appropriate federal regulatory agency. In addition, designer should investigate the status of adjacent wetlands to determine if the discharge from the constructed wetland will change the hydroperiod of a downstream natural wetland (see Cappiella et al., 2006 for guidance on minimizing stormwater discharges to existing wetlands).

Regulatory Status. Constructed wetlands built for the express purpose of stormwater treatment are generally not considered jurisdictional wetlands.

Perennial Streams. Locating a constructed wetland along or within a perennial stream will require both Section 401 and Section 404 permits from the state or federal regulatory authority.

Community and Environmental Concerns. In addition to the community and environmental concerns that exist for stormwater ponds, stormwater wetlands can generate the following to be addressed during design:

- **Aesthetics and Habitat.** Constructed wetlands can create wildlife habitat and can also become an attractive community feature. Designers should think carefully about how the wetland plant community will evolve over time, since the future plant community seldom resembles the one initially planted.
- **Existing Forests.** Given the large footprint of a constructed wetland, there is a strong chance that the construction process may result in extensive tree clearing. The designer should preserve mature trees during the facility layout, and he/she may consider creating a wooded wetland (see Cappiella et al., 2006). In the District of Columbia a permit is required to remove a tree with a circumference greater than 55-inches on private lands. A permit is required to prune or remove any street tree between the sidewalk and the curb. These permits are issued by the District Department of Transportation, Urban Forestry Administration (UFA).
- **Safety Risk.** Constructed wetlands are safer than other types of ponds, although forebays and micropools must be designed with aquatic benches to reduce safety risks.
- **Mosquito Risk.** Mosquito control can be a concern for stormwater wetlands if they are under-sized or have a small contributing drainage area. Deepwater zones serve to keep mosquito populations in check by providing habitat for fish and other pond life that prey on mosquito larvae. Few mosquito problems are reported for well designed, properly sized and frequently maintained constructed wetlands; however, no design can eliminate them completely. Simple precautions can be taken to minimize mosquito breeding habitat within constructed wetlands (e.g., constant inflows, benches that create habitat for natural predators, and constant pool elevations—MSSC, 2005).

3.11.2 Wetland Conveyance Criteria

- The slope profile within individual wetland cells should generally be flat from inlet to outlet (adjusting for microtopography). The recommended maximum elevation drop between wetland cells is 1 foot or less.
- Since most constructed wetlands are on-line facilities, they need to be designed to safely pass the maximum design storm (e.g., the 15-year and 100-year design storms). While the ponding depths for the more frequent 2-year storm are limited in order to avoid adverse impacts to the planting pallet, the overflow for the less frequent 15- and 100-year storms

must likewise be carefully designed to minimize the depth of ponding. A maximum depth of 4 feet over the wetland pool is recommended.

- While many different options are available for setting the normal pool elevation, it is strongly recommended that removable flashboard risers be used, given their greater operational flexibility to adjust water levels following construction (see Hunt et al, 2007). Also, a weir can be designed to accommodate passage of the larger storm flows at relatively low ponding depths.

3.11.3 Wetland Pretreatment Criteria

Sediment regulation is critical to sustain stormwater wetlands. Consequently, a forebay shall be located at the inlet, and a micropool shall be located at the outlet (A micropool is a three to six foot deep pool used to protect the low-flow pipe from clogging and to prevent sediment resuspension). Forebays are designed in the same manner as stormwater ponds (see Section 3.10.3 Pond Pretreatment Criteria). The design of forebays should consider the possibility of heavy trash loads from public areas.

3.11.4 Wetland Design Criteria

Internal Design Geometry. Research and experience have shown that the internal design geometry and depth zones are critical in maintaining the pollutant removal capability and plant diversity of stormwater wetlands. Wetland performance is enhanced when the wetland has multiple cells, longer flowpaths, and a high ratio of surface area to volume. Whenever possible, constructed wetlands should be irregularly shaped with long, sinuous flow paths. The following design elements are required for stormwater wetlands:

Multiple-Cell Wetlands. Wetlands can be divided into at least four internal sub-cells of different elevations: the forebay, a micro-pool outlet, and two additional cells. Cells can be formed by sand berms (anchored by rock at each end), back-filled coir fiber logs, or forested peninsulas (extending as wedges across 95 percent of the wetland width). The vegetative target is to ultimately achieve a 50-50 mix of emergent and forested wetland vegetation within all four cells.

The first cell (the forebay) is deeper and is used to receive runoff from the pond cell or the inflow from a pipe or open channel and distribute it as sheetflow into successive wetland cells. The surface elevation of the second cell is the normal pool elevation. It may contain a forested island or a sand wedge channel to promote flows into the third cell, which is 3 to 6 inches lower than the normal pool elevation. The purpose of the wetland cells is to create an alternating sequence of aerobic and anaerobic conditions to maximize pollutant removal. The fourth wetland cell is located at the discharge point and serves as a micro-pool with an outlet structure or weir.

Extended Detention Ponding Depth. When extended detention is provided for management of larger storm events, the total ED volume shall not comprise more than 50 percent of the total volume stored by the wetland, and its maximum water surface elevation shall not extend more than three feet above the normal pool.

Deep Pools. Approximately 25 percent of the wetland surface area must be provided in at least three deeper pools—located at the inlet (forebay), center, and outlet (micropool) of the wetland—with each pool having a depth of from 18 to 48 inches. Refer to the sizing based on water balance below for additional guidance on the minimum depth of the deep pools.

High Marsh Zone. Approximately 70 percent of the wetland surface area must exist in the high marsh zone (-6 inches to +6 inches, relative to the normal pool elevation).

Transition Zone. The low marsh zone is no longer an acceptable wetland zone, and is only allowed as a short transition zone from the deeper pools to the high marsh zone(-6 to -18 inches below the normal pool elevation). In general, this transition zone should have a maximum slope of 5H:1V (or preferably flatter) from the deep pool to the high marsh zone. It is advisable to install biodegradable erosion control fabrics or similar materials during construction to prevent erosion or slumping of this transition zone.

Flow Path. In terms of the flow path, there are two design objectives:

- The overall flow path through the wetland can be represented as the length-to-width ratio OR the flow path ratio. A minimum overall flow path of 2:1 must be provided across the stormwater wetland.
- The shortest flow path represents the distance from the closest inlet to the outlet. The ratio of the shortest flow path to the overall length must be at least 0.5. 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 must constitute no more than 20 percent of the total contributing drainage area.

Side Slopes. Side slopes for the wetland should generally have gradients of 4H:1V or flatter. These mild slopes promote better establishment and growth of the wetland vegetation. They also contribute to easier maintenance and a more natural appearance.

Micro-Topographic Features. Stormwater wetlands must have internal structures that create variable micro-topography, which is defined as a mix of above-pool vegetation, shallow pools, and deep pools that promote dense and diverse vegetative cover.

Constructed Wetland Material Specifications. Wetlands are generally constructed with materials obtained on-site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and geotextile fabric for lining banks or berms. Plant stock should be nursery grown, unless otherwise approved, and must be healthy and vigorous native species free from defects, decay, disfiguring roots, sun-scald, injuries, abrasions, diseases, insects, pests, and all forms of infestations or objectionable disfigurements, as determined by DDOE.

Wetland Sizing. Constructed wetlands can be designed to capture and treat the remaining stormwater discharged from upstream practices from the design storm (SWRv). Additionally, wetlands can be sized to control peak flow rates from the 2-year and 15-year frequency storm event or other design storm. Design calculations must ensure that the post-development peak discharge does not exceed the predevelopment peak discharge. See Section 2.7 Hydrology Methods for a summary of acceptable hydrological methodologies and models.

For treatment train designs where upland practices are utilized for treatment of the SWRv, designers can use a site-adjusted Rv or CN that reflects the volume reduction of upland practices to compute the Qp_2 and Qp_{15} that must be treated by the wetland.

The wetland permanent pools (volume stored in deep pools and pool depths) must be sized to store a volume equivalent to the SWRv or design volume.

The storage volume (Sv) of the practice is equal to the volume provided by the wetland permanent pool (Equation 3.26). The total Sv cannot exceed the SWRv.

Equation 3.26 Wetland Storage Volume

$$Sv = \text{Wetland permanent pool volume}$$

Sizing for Minimum Pool Depth. Initially, it is recommended that there be no minimum drainage area requirement for the system, although it may be necessary to calculate a water balance for the wet pond cell when its CDA is less than 10 acres (Refer to Section 3.10 Stormwater Ponds).

Similarly, if the hydrology for the constructed wetland is not supplied by groundwater or dry weather flow inputs, a simple water balance calculation must be performed, using Equation 3.27 (Hunt et al., 2007), to assure the deep pools will not go completely dry during a 30 day summer drought.

Equation 3.27 Water Balance for Acceptable Water Depth in a Stormwater Wetland

$$DP = \left(RF_m \times EF \times \frac{WS}{WL} \right) - \left(ET - INF - RS \right)$$

where:

DP	=	depth of pool (in.)
RF_m	=	monthly rainfall during drought (in.)
EF	=	fraction of rainfall that enters the stormwater wetland (in.) (CDA × Rv)
WS/WL	=	ratio of contributing drainage area to wetland surface area
ET	=	summer evapotranspiration rate (in.) (assume 8 in.)
INF	=	monthly infiltration loss (assume 7.2 inches at 0.01 in./hr)
RES	=	reservoir of water for a factor of safety (assume 6 in.)

Using Equation 3.28, setting the groundwater and (dry weather) base flow to zero and assuming a worst case summer rainfall of 0 inches, the minimum depth of the pool calculates as follows (Equation 3.28):

Equation 3.28 Minimum Depth of the Permanent Pool

Depth of Pool (DP) = 0 in. (*RFm*) – 8 in. (*ET*) – 7.2 in. (*INF)* – 6 in. (*RES*) = 21.2 in.

Therefore, unless there is other input, such as base flow or groundwater, the minimum depth of the pool should be at least 22 inches (rather than the 18-inch minimum depth noted in Section 3.11.4 and depicted in Figure 3.39).

3.11.5 Wetland Construction Sequence

The construction sequence for stormwater wetlands depends on site conditions, design complexity, and the size and configuration of the proposed facility. The following two-stage construction sequence is recommended for installing an on-line wetland facility and establishing vigorous plant cover.

Stage 1 Construction Sequence: Wetland Facility Construction.

Step 1: **Stabilize Drainage Area.** Stormwater wetlands should only be constructed after the contributing drainage area to the wetland is completely stabilized. If the proposed wetland site will be used as a sediment trap or basin during the construction phase, the construction notes must clearly indicate that the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 2: **Assemble Construction Materials On-site.** Inspect construction materials to insure they conform to design specifications, and prepare any staging areas.

Step 3: **Clear and Strip.** Bring the project area to the desired sub-grade.

Step 4: **Install Soil Erosion and Sediment Control Measures** prior to construction, including sediment basins and stormwater diversion practices. All areas surrounding the wetland that are graded or denuded during construction of the wetland are to be planted with turf grass, native plant materials or other approved methods of soil stabilization. Grass sod is preferred over seed to reduce seed colonization of the wetland. During construction the wetland must be separated from the contributing drainage area so that no sediment flows into the wetland areas. In some cases, a phased or staged soil erosion and sediment control plan (SESCP) may be necessary to divert flow around the stormwater wetland area until installation and stabilization are complete.

Step 5: **Excavate the Core Trench for the Embankment and Install the Spillway Pipe.**

Step 6: **Install the Riser or Outflow Structure** and ensure that the top invert of the overflow weir is constructed level and at the proper design elevation (flashboard risers are strongly recommended by Hunt et al, 2007).

Step 7: **Construct the Embankment and any Internal Berms** in 8 to 12-inch lifts and compacted with appropriate equipment.

Step 8: **Excavate and Grade.** Survey to achieve the appropriate elevation and designed contours for the bottom and side slopes of the wetland. This is normally done by "roughing up" the interim elevations with a skid loader or other similar equipment to achieve the desired topography across the wetland. Spot surveys should be made to ensure that the interim elevations are 3 to 6 inches below the final elevations for the wetland.

Step 9: **Install Micro-Topographic Features and Soil Amendments** within wetland area. Since most stormwater wetlands are excavated to deep sub-soils, they often lack the nutrients and organic matter needed to support vigorous growth of wetland plants. It is therefore essential to add sand, compost, topsoil or wetland mulch to all depth zones in the wetland. The importance of soil amendments in excavated wetlands cannot be over-emphasized; poor survival and future wetland coverage are likely if soil amendments are not added. The planting soil should be a high organic content loam or sandy loam, placed by mechanical methods, and spread by hand. Planting soil depth should be at least 4 inches for shallow wetlands. No machinery should be allowed to traverse over the planting soil during or after construction. Planting soil should be tamped as directed in the design specifications, but it should not be overly compacted. After the planting soil is placed, it should be saturated and allowed to settle for at least one week prior to installation of plant materials.

Step 10: **Construct the Emergency Spillway.** The emergency spillway must be constructed in cut or structurally stabilized soils.

Step 11: **Install Outlet Pipes**. The installation of outlet pipes must include a the downstream rip-rap protection apron.

Step 12: **Stabilize Exposed Soils** with temporary seed mixtures appropriate for a wetland environment. All wetland features above the normal pool elevation should be temporarily stabilized by hydro-seeding or seeding over straw.

Stage 2 Construction Sequence: Establishing the Wetland Vegetation.

Step 13: **Finalize the Wetland Landscaping Plan.** At this stage the engineer, landscape architect, and wetland expert work jointly to refine the initial wetland landscaping plan after the stormwater wetland has been constructed. Several weeks of standing time is needed so that the designer can more precisely predict the following two things:

- Where the inundation zones are located in and around the wetland; and
- Whether the final grade and wetland microtopography will persist over time.

This allows the designer to select appropriate species and additional soil amendments, based on field confirmation of soils properties and the actual depths and inundation frequencies occurring within the wetland.

Step 14: **Open Up the Wetland Connection.** Once the final grades are attained, the pond and/or contributing drainage area connection should be opened to allow the wetland cell to fill up to the normal pool elevation. Gradually inundate the wetland erosion of unplanted features. Inundation must occur in stages so that deep pool and high marsh plant materials can be placed effectively and safely. Wetland planting areas should be at least partially inundated during planting to promote plant survivability.

Step 15: **Measure and Stake Planting Depths** at the onset of the planting season. Depths in the wetland should be measured to the nearest inch to confirm the original planting depths of the planting zone. At this time, it may be necessary to modify the plan to reflect altered depths or a change in the availability of wetland plant stock. Surveyed planting zones should be marked on the as-built or design plan, and their locations should also be identified in the field, using stakes or flags.

Step 16: **Propagate the Stormwater Wetland.** Three techniques are used in combination to propagate the emergent community over the wetland bed:

1. **Initial Planting of Container-Grown Wetland Plant Stock.** The transplanting window extends from early April to mid-June. Planting after these dates is quite chancy, since emergent wetland plants need a full growing season to build the root reserves needed to get through the winter. It is recommended that plants be ordered at least 6 months in advance to ensure the availability and on-time delivery of desired species.
2. **Broadcasting Wetland Seed Mixes.** The higher wetland elevations should be established by broadcasting wetland seed mixes to establish diverse emergent wetlands. Seeding of switchgrass or wetland seed mixes as a ground cover is recommended for all zones above 3 inches below the normal pool elevation. Hand broadcasting or hydroseeding can be used to spread seed, depending on the size of the wetland cell.
3. **Allowing "Volunteer Wetland Plants to Establish on Their Own.** The remaining areas of the stormwater wetland will eventually (within 3 to 5 years) be colonized by volunteer species from upstream or the forest buffer.

Step 17: **Install Goose Protection to Protect Newly Planted or Newly Growing Vegetation.** This is particularly critical for newly established emergents and herbaceous plants, as predation by Canada geese can quickly decimate wetland vegetation. Goose protection can consist of netting, webbing, or string installed in a crisscross pattern over the surface area of the wetland, above the level of the emergent plants.

Step 18: **Plant the Wetland Fringe and Buffer Area.** This zone generally extends from 1 to 3 feet above the normal pool elevation (from the shoreline fringe to about half of the maximum water surface elevation for the 2-year storm). Consequently, plants in this zone are infrequently inundated (5 to 10 times per year), and must be able to tolerate both wet and dry periods.

Construction Supervision. Supervision during construction is recommended to ensure that stormwater wetlands are properly constructed and established. Multiple site visits and inspections by a qualified professional are recommended during the following stages of the wetland construction process:

- Preconstruction meeting
- Initial site preparation including the installation of project soil erosion and sediment control measures
- Excavation/Grading (e.g., interim/final elevations)
- Wetland installation (e.g., microtopography, soil amendments and staking of planting zones)

- Planting Phase (with an experienced landscape architect or wetland expert)
- Final Inspection (develop a punch list for facility acceptance)

DDOE's construction phase inspection checklist for Constructed Wetlands can be found in Appendix K.

3.11.6 Wetland Landscaping Criteria

An initial wetland landscaping plan is required for any stormwater wetland and should be jointly developed by the engineer and a wetlands expert or experienced landscape architect. The plan should outline a detailed schedule for the care, maintenance and possible reinforcement of vegetation in the wetland and its buffer for up to 10 years after the original planting.

The plan should outline a realistic, long-term planting strategy to establish and maintain desired wetland vegetation. The plan should indicate how wetland plants will be established within each inundation zone (e.g., wetland plants, seed-mixes, volunteer colonization, and tree and shrub stock) and whether soil amendments are needed to get plants started. At a minimum, the plan should contain the following:

- Plan view(s) with topography at a contour interval of no more than 1 foot and spot elevations throughout the cell showing the wetland configuration, different planting zones (e.g., high marsh, deep water, upland), microtopography, grades, site preparation, and construction sequence.
- A plant schedule and planting plan specifying emergent, perennial, shrub and tree species, quantity of each species, stock size, type of root stock to be installed, and spacing. To the degree possible, the species list for the constructed wetland should contain plants found in similar local wetlands.

The following general guidance is provided:

- **Use Native Species Where Possible.** Table 3.47 provides a list of common native shrub and tree species and Table 3.48 provides a list of common native emergent, submergent and perimeter plant species, all of which have proven to do well in stormwater wetlands in the mid-Atlantic region and are generally available from most commercial nurseries (consult DDOE's webpage for information on area suppliers). Other native species can be used that appear in state-wide plant lists. The use of native species is strongly encouraged, but in some cases, non-native ornamental species may be added as long as they are not invasive. Invasive species such as cattails, Phragmites and purple loosestrife must not be planted.
- **Match Plants to Inundation Zones.** The various plant species shown in Table 3.47 and Table 3.48 should be matched to the appropriate inundation zone. The first four inundation zones are particularly applicable to stormwater wetlands, as follows:

  Zone 1 -6 inches to -12 inches below the normal pool elevation

  Zone 2 -6 inches to the normal pool elevation

  Zone 3 From the normal pool elevation to + 12 inches above it

  Zone 4 +12 inches to + 36 inches above the normal pool elevation (i.e., above ED Zone)

Note: The Low Marsh Zone (-6 inches to -18 inches below the normal pool elevation) has been dropped since experience has shown that few emergent wetland plants flourish in this deeper zone.

- **Aggressive Colonizers.** To add diversity to the wetland, 5 to 7 species of emergent wetland plants should be planted, using at least four emergent species designated as aggressive colonizers (shown in bold in Table 3.48). No more than 25 percent of the high marsh wetland surface area needs to be planted. If the appropriate planting depths are achieved, the entire wetland should be colonized within three years. Individual plants should be planted 18 inches on center within each single species "cluster".

Table 3.47 Popular, Versatile, and Available Native Trees and Shrubs for Constructed Wetlands

Shrubs		Trees	
Common and *Scientific* Names	**Zone[1]**	**Common and *Scientific* Names**	**Zone[1]**
Button Bush *(Cephalanthus occidentalis)*	2, 3	Atlantic White Cedar *(Charnaecyparis thyoides)*	2, 3
Common Winterberry *(Ilex verticillatta)*	3, 4	Bald Cypress *(Taxodium distichum)*	2, 3
Elderberry *(Sambucus canadensis)*	3	Black Willow *(Salix nigra)*	3, 4
Indigo Bush *(Amorpha fruticosa)*	3	Box Elder *(Acer Negundo)*	2, 3
Inkberry *(Ilex glabra)*	2, 3	Green Ash *(Fraxinus pennsylvanica)*	3, 4
Smooth Alder *(Alnus serrulata)*	2, 3	Grey Birch *(Betula populifolia)*	3, 4
Spicebush *(Lindera benzoin)*	3, 4	Red Maple *(Acer rubrum)*	3, 4
Swamp Azalea *(Azalea viscosum)*	2, 3	River Birch *(Betula nigra)*	3, 4
Swamp Rose *(Rosa palustris)*	2, 3	Swamp Tupelo *(Nyssa biflora)*	2, 3
Sweet Pepperbush *(Clethra ainifolia)*	2, 3	Sweetbay Magnolia *(Magnolia virginiana)*	3, 4
		Sweetgum *(Liquidambar styraciflua)*	3, 4
		Sycamore *(Platanus occidentalis)*	3, 4
		Water Oak *(Quercus nigra)*	3, 4
		Willow Oak *(Quercus phellos)*	3,4

[1]Zone 1: -6 inches to -12 inches ***OR*** -18 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 inches to +36 inches; above ED zone
Source: Virginia DCR Stormwater Design Specification No. 13: Constructed Wetlands Version 1.8. 2010.

Table 3.48 Popular, Versatile, and Available Native Emergent and Submergent Vegetation for Constructed Wetlands

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Arrow Arum *(Peltandra virginica)*	2	Emergent	Up to 1 ft	High; berries are eaten by wood ducks	Full sun to partial shade
Broad-Leaf Arrowhead (Duck Potato) *(Saggitaria latifolia)*	2	Emergent	Up to 1 ft	Moderate; tubers and seeds eaten by ducks	Aggressive colonizer
Blueflag Iris* *(Iris versicolor)*	2, 3	Emergent	Up to 6 in.	Limited	Full sun (to flower) to partial shade
Broomsedge *(Andropogon virginianus)*	2, 3	Perimeter	Up to 3 in.	High; songbirds and browsers; winter food and cover	Tolerant of fluctuating water levels and partial shade
Bulltongue Arrowhead *(Sagittaria lancifolia)*	2, 3	Emergent	0–24 in.	Waterfowl, small mammals	Full sun to partial shade
Burreed *(Sparganium americanum)*	2, 3	Emergent	0–6 in.	Waterfowl, small mammals	Full sun to partial shad
Cardinal Flower * *(Lobelia cardinalis)*	3	Perimeter	Periodic inundation	Attracts hummingbirds	Full sun to partial shade
Common Rush *(Juncus spp.)*	2, 3	Emergent	Up to 12 in.	Moderate; small mammals, waterfowl, songbirds	Full sun to partial shade
Common Three Square *(Scipus pungens)*	2	Emergent	Up to 6 in.	High; seeds, cover, waterfowl, songbirds	Fast colonizer; can tolerate periods of dryness; full sun; high metal removal
Duckweed (*Lemna sp.*	1, 2	Submergent / Emergent	Yes	High; food for waterfowl and fish	May biomagnify metals beyond concentrations found in the water
Joe Pye Weed *(Eupatorium purpureum)*	2, 3	Emergent	Drier than other Joe-Pye Weeds; dry to moist areas; periodic inundation	Butterflies, songbirds, insects	Tolerates all light conditions
Lizard's Tail *(Saururus cernus)*	2	Emergent	Up to 1 ft	Low; except for wood ducks	Rapid growth; shade-tolerant
Marsh Hibiscus *(Hibiscus moscheutos)*	2, 3	Emergent	Up to 3 in.	Low; nectar	Full sun; can tolerate periodic dryness
Pickerelweed *(Pontederia cordata)*	2, 3	Emergent	Up to 1 ft	Moderate; ducks, nectar for butterflies	Full sun to partial shade
Pond Weed *(Potamogeton pectinatus)*	1	Submergent	Yes	Extremely high; waterfowl, marsh and shore birds	Removes heavy metals from the water
Rice Cutgrass *(Leersia oryzoides)*	2, 3	Emergent	Up to 3 in.	High; food and cover	Prefers full sun, although tolerant of shade; shoreline stabilization

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Sedges *(Carex spp.)*	2, 3	Emergent	Up to 3 in.	High; waterfowl, songbirds	Wetland and upland species
Softstem Bulrush *(Scipus validus)*	2, 3	Emergent	Up to 2 ft	Moderate; good cover and food	Full sun; aggressive colonizer; high pollutant removal
Smartweed *(Polygonum spp.)*	2	Emergent	Up to 1 ft	High; waterfowl, songbirds; seeds and cover	Fast colonizer; avoid weedy aliens, such as *P. Perfoliatum*
Spatterdock *(Nuphar luteum)*	2	Emergent	Up to 1.5 ft	Moderate for food, but High for cover	Fast colonizer; tolerant of varying water levels
Switchgrass *(Panicum virgatum)*	2, 3, 4	Perimeter	Up to 3 in.	High; seeds, cover; waterfowl, songbirds	Tolerates wet/dry conditions
Sweet Flag * *(Acorus calamus)*	2, 3	Perimeter	Up to 3 in.	Low; tolerant of dry periods	Tolerates acidic conditions; not a rapid colonizer
Waterweed *(Elodea canadensis)*	1	Submergent	Yes	Low	Good water oxygenator; high nutrient, copper, manganese and chromium removal
Wild celery *(Valisneria americana)*	1	Submergent	Yes	High; food for waterfowl; habitat for fish and invertebrates	Tolerant of murkey water and high nutrient loads
Wild Rice *(Zizania aquatica)*	2	Emergent	Up to 1 ft	High; food, birds	Prefers full sun
Woolgrass *(Scirpus cyperinus)*	3, 4	Emergent	yes	High: waterfowl, small mammals	Fresh tidal and non-tidal, swamps, forested wetlands, meadows, ditches

[1]Zone 1: -6 inches to -12 inches ***OR*** -18 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 inches to +36 inches; above ED zone
*****Not a major colonizer, but adds color (Aggressive colonizers are shown in **bold** type)
Source: Virginia DCR Stormwater Design Specification No. 13: Constructed Wetlands Version 1.8. 2010.

- **Suitable Tree Species.** The major shift in stormwater wetland design is to integrate trees and shrubs into the design, in tree islands, peninsulas, and fringe buffer areas. Deeper-rooted trees and shrubs that can extend to the stormwater wetland's local water table are important for creating a mixed wetland community. Table 3.47 above presents some recommended tree and shrub species in the mid-Atlantic region for different inundation zones. A good planting strategy includes varying the size and age of the plant stock to promote a diverse structure. Using locally grown container or bare root stock is usually the most successful approach, if planting in the spring. It is recommended that buffer planting areas be over-planted with a small stock of fast growing successional species to achieve quick canopy closure and shade out invasive plant species. Trees may be planted in clusters to share rooting space on compacted wetland side-slopes. Planting holes should be amended with compost (a 2:1 ratio of loose soil to compost) prior to planting.

- **Pre- and Post-Nursery Care.** Plants should be kept in containers of water or moist coverings to protect their root systems and keep them moist when in transporting them to the planting location. As much as six to nine months of lead time may be needed to fill orders for wetland plant stock from aquatic plant nurseries. Consult DDOE's webpage for information on area suppliers.

3.11.7 Wetland Maintenance Criteria

Successful establishment of constructed wetland areas requires that the following tasks be undertaken in the first two years:

- **Initial Inspections.** During the first 6 months following construction, the site should be inspected by a qualified professional at least twice after storm events that exceed 1/2 inch of rainfall.
- **Spot Reseeding.** Inspections should include looking for bare or eroding areas in the contributing drainage area or around the wetland buffer, and make sure they are immediately stabilized with grass cover.
- **Watering.** Trees planted in the buffer and on wetland islands and peninsulas need watering during the first growing season. In general, consider watering every three days for first month, and then weekly during the first growing season (April - October), depending on rainfall.
- **Reinforcement Plantings.** Regardless of the care taken during the initial planting of the wetland and buffer, it is probable that some areas will remain unvegetated and some species will not survive. Poor survival can result from many unforeseen factors, such as predation, poor quality plant stock, water level changes, drought. Thus, it is advisable to budget for an additional round of reinforcement planting after one or two growing seasons. Construction contracts should include a care and replacement warranty extending at least two growing seasons after initial planting, to selectively replant portions of the wetland that fail to fill in or survive. If a minimum coverage of 50 percent is not achieved in the planted wetland zones after the second growing season, a reinforcement planting will be required.

Managing vegetation is an important ongoing maintenance task at every constructed wetland and for each inundation zone. Following the design criteria above should result in a reduced need for regular mowing of the embankment and access roads. Vegetation within the wetland, however, will require some annual maintenance.

Designers should expect significant changes in wetland species composition to occur over time. Inspections should carefully track changes in wetland plant species distribution over time. Invasive plants should be dealt with as soon as they begin to colonize the wetland. As a general rule, control of undesirable invasive species (e.g., cattails and Phragmites) should commence when their coverage exceeds more than 15 percent of a wetland cell area. Although the application of herbicides is not recommended, some types (e.g., Glyphosate) have been used to control cattails with some success. Extended periods of dewatering may also work, since early manual removal provides only short-term relief from invasive species. While it is difficult to exclude invasive species completely from stormwater wetlands, their ability to take over the entire wetland can be reduced if the designer creates a wide range of depth zones and a complex internal structure within the wetland.

Thinning or harvesting of excess forest growth may be periodically needed to guide the forested wetland into a more mature state. Vegetation may need to be harvested periodically if the constructed wetland becomes overgrown. Thinning or harvesting operations should be scheduled to occur approximately 5 and 10 years after the initial wetland construction. Removal of woody species on or near the embankment and maintenance access areas should be conducted every 2 years.

Designers should refer to Section 3.10.7 Pond Maintenance Criteria for additional maintenance responsibilities associated with wetlands. Ideally, maintenance of constructed wetlands should be driven by annual inspections by a qualified professional that evaluate the condition and performance of the wetland. Based on inspection results, specific maintenance tasks will be triggered. DDOE's maintenance inspection checklist for stormwater wetlands and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.11.8 Wetland Stormwater Compliance Calculations

Stormwater wetlands receive 10 percent retention value and are an accepted total suspended solids (TSS) treatment practice for the amount of storage volume (Sv) provided by the BMP (Table 3.49).

Table 3.49 Wetland Retention Value and Pollutant Removal

Retention Value	$= 0.1 \times Sv$
Accepted TSS Treatment Practice	Yes

3.11.9 References

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.

Hunt, W., M. Burchell, J. Wright and K. Bass. 2007. "Stormwater Wetland Design Update: Zones, Vegetation, Soil and Outlet Guidance." Urban Waterways. North Carolina State Cooperative Extension Service. Raleigh, NC.

Minnesota Stormwater Steering Committee (MSSC). 2005. Minnesota Stormwater Manual. Emmons & Oliver Resources, Inc. Minnesota Pollution Control Agency. St. Paul, MN.

Virginia DCR Stormwater Design Specification No. 13: Constructed Wetlands Version 1.8. 2010.

3.12 Storage Practices

Definition. Storage practices are explicitly designed to provide stormwater detention (2-year, 15-year, and/or flood control). Design variants include:

S-1 Underground detention vaults and tanks

S-2 Dry detention ponds

S-3 Rooftop storage

S-4 Stone storage under permeable pavement or other BMPs

Detention vaults are box-shaped underground stormwater storage facilities typically constructed with reinforced concrete. Detention tanks are underground storage facilities typically constructed with large diameter metal or plastic pipe. Both serve as an alternative to surface dry detention for stormwater quantity control, particularly for space-limited areas where there is not adequate land for a dry detention basin or multi-purpose detention area. Prefabricated concrete vaults are available from commercial vendors. In addition, several pipe manufacturers have developed packaged detention systems.

Dry detention ponds are widely applicable for most land uses and are best suited for larger drainage areas an outlet structure restricts stormwater flow so it backs up and is stored within the basin. The temporary ponding reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on the bed and banks of the receiving stream.

Storage practices do not receive any stormwater retention or treatment volume and should be considered only for management of larger storm events. Storage practices are not considered an acceptable practice to meet the SWRv. Storage practices must be combined with a separate facility to meet these requirements. Upland practices can be used to satisfy some or all of the stormwater retention requirements at many sites, which can help to reduce the footprint and volume of storage practices.

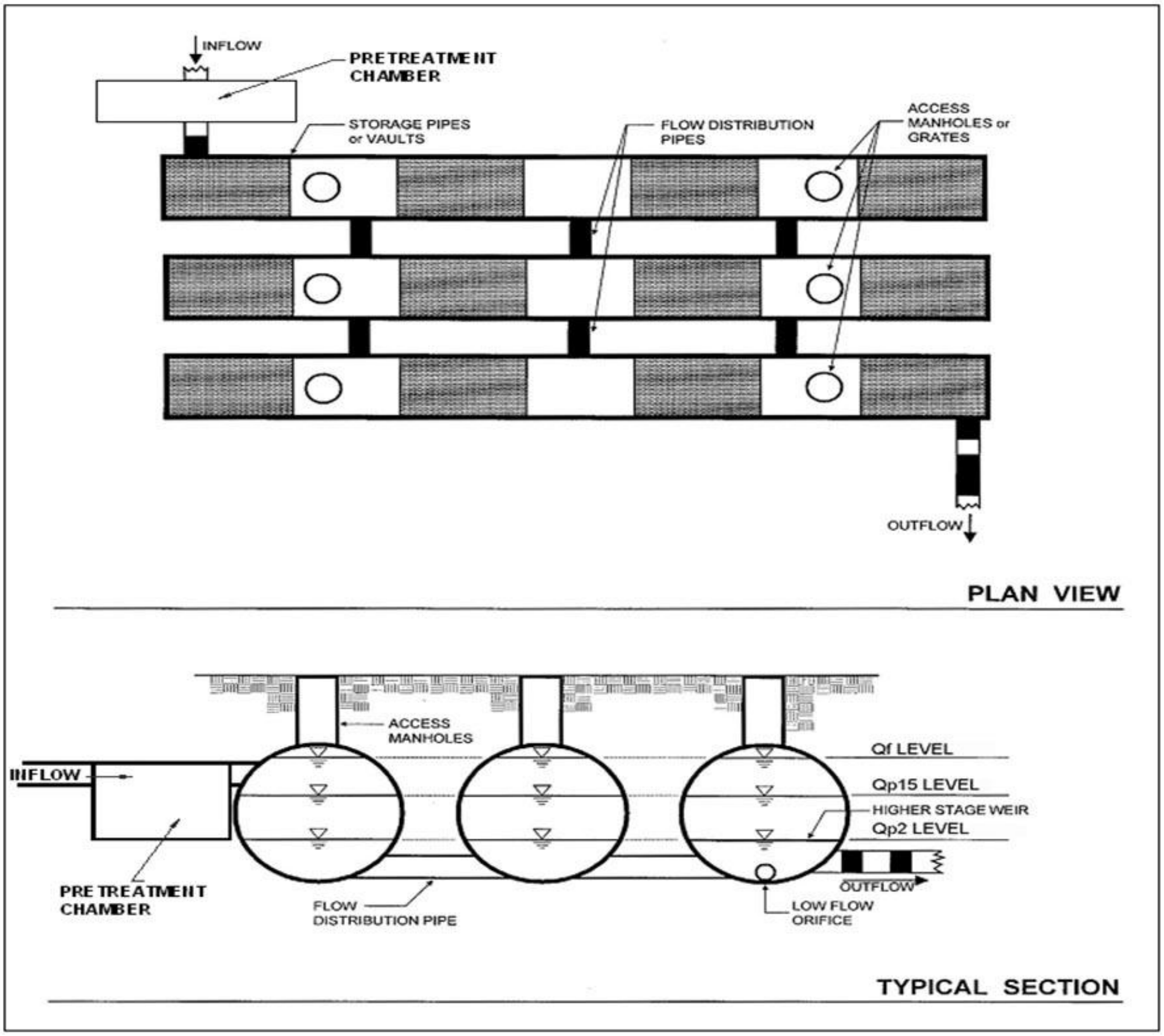
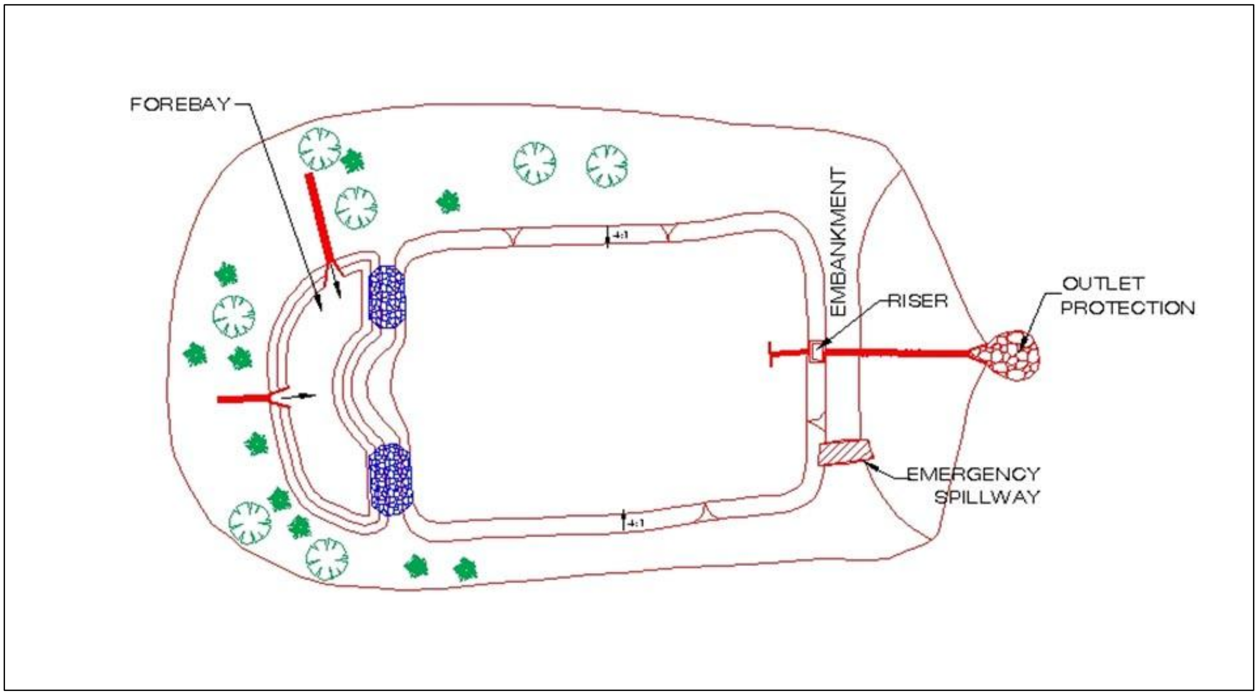


Figure 3.40 Example of an underground detention vault and/or tank (S-1).



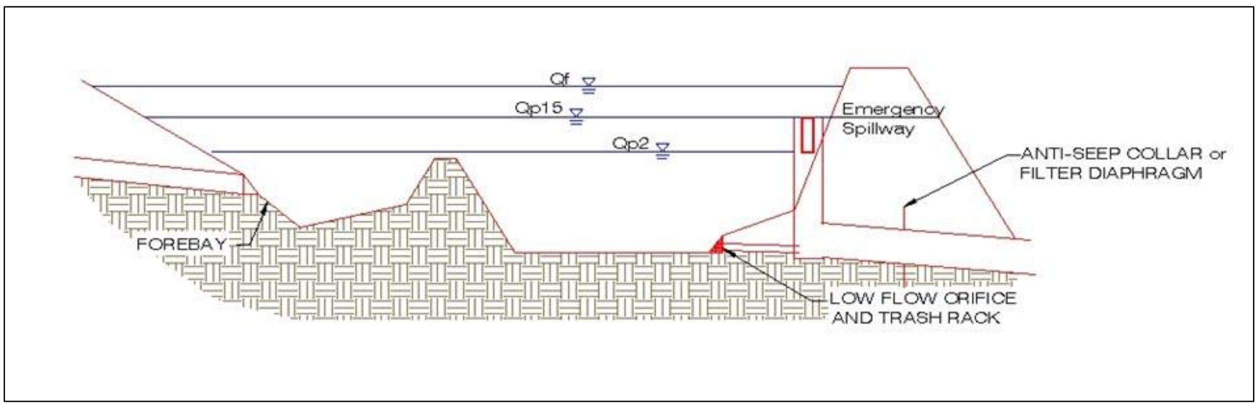


Figure 3.41 Example of a dry detention pond (S-2).

3.12.1 Storage Feasibility Criteria

The following feasibility issues need to be evaluated when storage practices are considered as the final practice in a treatment train:

Space Required. A typical storage practices requires a footprint of 1 to 3 percent of its contributing drainage area, depending on the depth of the pond or storage vault (i.e., the deeper the practice, the smaller footprint needed).

Contributing Drainage Area. A contributing drainage area of at least 10 acres is preferred for dry ponds in order to keep the required orifice size from becoming a maintenance problem. Designers should be aware that small “pocket” ponds will typically (1) have very small orifices that will be prone to clogging, (2) experience fluctuating water levels such that proper stabilization with vegetation is very difficult, and (3) generate more significant maintenance problems.

Underground detention systems can be located downstream of other structural stormwater controls providing treatment of the design storm. For treatment train designs where upland practices are utilized for treatment of the SWRv, designers can use a site-adjusted Rv or CN that reflects the volume reduction of upland practices and likely reduce the size and cost of detention (see Storage Practice Sizing in Section 3.12.4 Storage Design Criteria).

The maximum contributing drainage area to be served by a single underground detention vault or tank is 25 acres.

Available Hydraulic Head. The depth of a storage practice is usually determined by the amount of hydraulic head available at the site (dimension between the surface drainage and the bottom elevation of the site). The bottom elevation is normally the invert of the existing downstream conveyance system to which the storage practice discharges. Depending on the size of the development and the available surface area of the basin, as much as 6 to 8 feet of hydraulic head may be needed for a dry detention practice to function properly for storage. An underground storage practice will require sufficient head room to facilitate maintenance—at least 5 feet depending on the design configuration.

Setbacks. To avoid the risk of seepage, storage practices must not be hydraulically connected to structure foundations. Setbacks to structures must be at least 10 feet and adequate water-proofing protection must be provided for foundations and basements.

Depth to Water Table and Bedrock. Dry ponds are not allowed if the water table or bedrock will be within 2 feet of the floor of the pond. For underground detention vaults and tanks, an anti-flotation analysis is required to check for buoyancy problems in the high water table areas.

Soils. The permeability of soils is seldom a design constraint for storage practices. Soil infiltration tests should be conducted at proposed dry pond sites to estimate infiltration rates and patterns, which can be significant in Hydrologic Soil Group (HSG) A soils and some group B soils. Infiltration through the bottom of the pond is typically encouraged unless it may potentially migrate laterally thorough a soil layer and impair the integrity of the embankment or other structure.

Structural Stability. Underground detention vaults and tanks must meet structural requirements for overburden support and traffic loading if appropriate as verified by shop drawings signed by an appropriately licensed professional.

Geotechnical Tests. At least one soil boring must be taken at a low point within the footprint of any proposed storage practice to establish the water table and bedrock elevations and evaluate soil suitability. A geotechnical investigation is required for all underground BMPs, including underground storage systems. Geotechnical testing requirements are outlined in Appendix O.

Utilities. For a dry pond system, no utility lines shall be permitted to cross any part of the embankment where the design water depth is greater than 2 feet. Typically, utilities require a minimum 5-foot horizontal clearance from storage facilities.

Perennial Streams. Locating dry ponds on perennial streams will require both a Section 401 and Section 404 permit from the appropriate state or federal regulatory agency.

3.12.2 Storage Conveyance Criteria

Designers must use accepted hydrologic and hydraulic routing calculations to determine the required storage volume and an appropriate outlet design for storage practices. See Section 2.7 Hydrology Methods for a summary of acceptable hydrological methodologies and models.

For management of the 2-year storm, a control structure with a trash rack designed to release the required predevelopment Qp_2 must be provided. Ideally, the channel protection orifice should have a minimum diameter of 3 inches in order to pass minor trash and debris. However, where smaller orifices are required, the orifice must be adequately protected from clogging by an acceptable external trash rack.

As an alternative, the orifice diameter may be reduced if internal orifice protection is used (i.e., a perforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wirecloth and a stone filtering jacket). Adjustable gate valves, weir manholes, and other structures designed for simple maintenance can also be used to achieve this equivalent diameter.

For overbank flood protection, an additional outlet is sized for Qp_{15} control and can consist of a weir, orifice, outlet pipe, combination outlet, or other acceptable control structure.

Riprap, plunge pools or pads, or other energy dissipaters are to be placed at the end of the outlet to prevent scouring and erosion and to provide a non-erosive velocity of flow from the structure to a water course. The design must specify an outfall that will be stable for the 15-year design storm event. The channel immediately below the storage practice outfall must be modified to prevent erosion. This is typically done by calculating channel velocities and flow depths, then placing appropriately sized riprap, over geotextile fabric, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps depending on the channel lining material). The storage practice geometry and outfall design may need to be altered in order to yield adequate channel velocities and flow.

Flared pipe sections that discharge at or near the stream invert or into a step pool arrangement should be used at the spillway outlet. An outfall analysis shall be included in the stormwater management plan showing discharge velocities down to the nearest downstream water course. Where indicated, the developer / contractor must secure an off-site drainage easement for any improvements to the downstream channel.

When the discharge is to a manmade pipe or channel system, the system must be adequate to convey the required design storm peak discharge.

If discharge daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of rip-rap should be avoided.

The final release rate of the facility shall be modified if any increase in flooding or stream channel erosion would result at a downstream structure, highway, or natural point of restricted streamflow (see Section 2.6 Additional Stormwater Management Requirements).

The following additional conveyance criteria apply to underground detention or ponds:

- **High Flow Bypass (underground detention).** An internal or external high flow bypass or overflow must be included in the underground detention designs to safely pass the extreme flood flow.
- **Primary Spillway (dry ponds).** The primary spillway shall be designed with acceptable anti-flotation, anti-vortex, and trash rack devices. The spillway must generally be accessible from dry land. When reinforced concrete pipe is used for the principal spillway to increase its longevity, “O”-ring gaskets (ASTM C-361) must be used to create watertight joints, and they should be inspected during installation.
- **Avoid Outlet Clogging (dry ponds).** The risk of clogging in outlet pipes with small orifices can be reduced by:
  - Providing a micropool at the outlet structure. For more information on micropool extended detention ponds see Section 3.10 Stormwater Ponds.
  - Installing a trash rack to screen the low-flow orifice.
  - Using a perforated pipe under a gravel blanket with an orifice control at the end in the riser structure.
- **Emergency Spillway (dry ponds).** Dry ponds must be constructed with overflow capacity to safely pass the 100-year design storm event through either the primary spillway or a vegetated or armored emergency spillway unless waived by DDOE.
- **Inlet Protection (dry ponds).** Inflow points into dry pond systems must be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (i.e., the 15-year storm event).

3.12.3 Storage Pretreatment Criteria

Dry Pond Pretreatment Forebay. A forebay must be located at each major inlet to a dry pond to trap sediment and preserve the capacity of the main treatment cell. The following criteria apply to dry pond forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel serving at least 10 percent of the storage practice’s contributing drainage area.
- The forebay consists of a separate cell, formed by an acceptable barrier (e.g., an earthen berm, concrete weir, gabion baskets, etc.).
- The forebay shall be sized to contain 0.1 inches per impervious acre of contributing drainage. The relative size of individual forebays should be proportional to the percentage of the total inflow to the dry pond.
- The forebay should be designed in such a manner that it acts as a level spreader to distribute runoff evenly across the entire bottom surface area of the main storage cell.

- Exit velocities from the forebay shall be non-erosive or an armored overflow shall be provided. Non-erosive velocities are 4 feet per second for the two-year event, and 6 feet per second for the 15-year event.
- The bottom of the forebay may be hardened (e.g., concrete, asphalt, or grouted riprap) in order to make sediment removal easier.
- Direct maintenance access for appropriate equipment shall be provided to the each forebay.

Underground Detention Pretreatment. A pretreatment structure to capture sediment, coarse trash and debris must be placed upstream of any inflow points to underground detention. A separate sediment sump or vault chamber sized to capture 0.1 inches per impervious acre of contributing drainage, or a proprietary structure with demonstrated capability of removing sediment and trash, should be provided at the inlet for underground detention systems that are in a treatment train with off-line water quality treatment structural controls. Refer to Section 3.13 for information on approved proprietary practices.

3.12.4 Storage Design Criteria

Dry Pond Internal Design Features. The following apply to dry pond design:

- **No Pilot Channels.** Dry 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 avoid scour, promote attenuation and, where possible, infiltration
- **Internal Slope.** The maximum longitudinal slope through the pond should be approximately 0.5 to 1 percent.
- **Side Slopes.** Side slopes within the dry pond should generally have a gradient of 3H:1V to 4H:1V. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance. Ponds with side slopes steeper than 5H:1V must be fenced and include a lockable gate.
- **Long Flow Path.** Dry pond designs should have an irregular shape and a long flow path distance from inlet to outlet to increase water residence time, treatment pathways, pond performance, and to eliminate short-cutting. In terms of flow path geometry, there are two design considerations: (1) the overall flow path through the pond, and (2) the length of the shortest flow path (Hirschman et al., 2009):
    - The overall flow path can be represented as the length-to-width ratio OR the flow path ratio. These ratios must be at least 2L:1W (3L:1W preferred). 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 0.4. 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 must constitute no more than 20 percent of the total contributing drainage area.

Safety Features. The following safety features must be considered for storage practices:

- The principal spillway opening must be designed and constructed to prevent access by small children.
- End walls above pipe outfalls greater than 48 inches in diameter must be fenced at the top of the wall to prevent a falling hazard.
- Storage practices must incorporate an additional 1 foot of freeboard above the emergency spillway, or 2 feet of freeboard if design has no emergency spillway, for the maximum Q_f design storm unless more stringent Dam Safety requirements apply.
- The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges
- Underground maintenance access should be locked at all times.

Maintenance Access. All storage practices shall be designed so as to be accessible to annual maintenance. Unless waived by the DDOE, a 5:1 slope and 15 foot wide entrance ramp is required for maintenance access to dry ponds. Adequate maintenance access must also be provided for all underground detention systems. Access must be provided over the inlet pipe and outflow structure with access steps. Access openings can consist of a standard 30-inch diameter frame, grate and solid cover, or a hinged door or removable panel.

Outlets. Trash racks shall be provided for low-flow pipes and for risers not having anti-vortex devices.

In order to reduce maintenance problems for small orifices, a standpipe design can be used that includes a smaller inner standpipe with the required orifice size, surrounded by a larger standpipe with multiple openings, and a gravel jacket surrounding the larger standpipe. This design will reduce the likelihood of the orifice being clogged by sediment.

Detention Vault and Tank Materials. Underground stormwater detention structures shall be composed of materials as approved by the DDOE. All construction joints and pipe joints shall be water tight. Cast-in-place wall sections must be designed as retaining walls. The maximum depth from finished grade to the vault invert is 20 feet. The minimum pipe diameter for underground detention tanks is 24 inches unless otherwise approved by DDOE. Manufacturer's specifications should be consulted for underground detention structures.

Anti-floatation Analysis for Underground Detention. Anti-flotation analysis is required to check for buoyancy problems in the high water table areas. Anchors shall be designed to counter the pipe and structure buoyancy by at least a 1.2 factor of safety.

Storage Practice Sizing. Storage facilities should be sized to control peak flow rates from the 2-year and 15-year frequency storm event or other design storm. Design calculations must ensure that the post-development peak discharge does not exceed the predevelopment peak discharge. See Section 2.7 Hydrology Methods for a summary of acceptable hydrological methodologies and models.

For treatment train designs where upland practices are utilized for treatment of the SWRv, designers can use a site-adjusted Rv or CN that reflects the volume reduction of upland practices to compute the Qp_2 and Qp_{15} that must be treated by the storage practice.

3.12.5 Storage Landscaping Criteria

No landscaping criteria apply to underground storage practices.

For dry ponds, a landscaping plan must be provided that indicates the methods used to establish and maintain vegetative coverage within the dry pond. Minimum elements of a plan include the following:

- Delineation of pondscaping zones within the pond
- Selection of corresponding plant species
- The planting plan
- The sequence for preparing the wetland bed, if one is incorporated with the Dry pond (including soil amendments, if needed)
- Sources of native plant material
- The planting plan should allow the pond to mature into a native forest in the right places, but yet keep mowable turf along the embankment and all access areas. The wooded wetland concept proposed by Cappiella et al., (2005) may be a good option for many dry ponds.
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.
- Avoid species that require full shade, or are prone to wind damage.

3.12.6 Storage Construction Sequence

Construction of underground storage systems must be in accordance with manufacturer's specifications. All runoff into the system should be blocked until the site is stabilized. The system must be inspected and cleaned of sediment after the site is stabilized.

The following is a typical construction sequence to properly install a dry pond. The steps may be modified to reflect different dry pond designs, site conditions, and the size, complexity and configuration of the proposed facility.

Step 1: **Use of Dry Pond for Soil Erosion and Sediment Control.** A dry pond may serve as a sediment basin during project construction. If this is done, the volume should be based on the more stringent sizing rule (soil erosion and sediment control requirement vs. water quality treatment requirement). Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction dry pond in mind. The bottom elevation of the dry pond should be lower than the bottom elevation of the temporary sediment basin. Appropriate procedures must be implemented to prevent discharge of turbid waters when the basin is being converted into a dry pond.

Step 2: **Stabilize the Drainage Area.** Dry ponds should only be constructed after the contributing drainage area to the pond is completely stabilized. If the propose dry pond site will be used as a sediment trap or basin during the construction phase, the construction notes must clearly indicate that the facility will be dewatered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 3: **Assemble Construction Materials On-site**. Inspect construction materials to insure they conform to design specifications, and prepare any staging areas.

Step 4: **Clear and Strip.** Bring the project area to the desired sub-grade.

Step 5: **Soil Erosion and Sediment Controls.** Install soil erosion and sediment control measures prior to construction, including temporary stormwater diversion practices. All areas surrounding the pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

Step 6: **Install the Spillway Pipe.** Ensure the top invert of the spillway pipe is set to design elevation.

Step 7: **Install the Riser or Outflow Structure.** Once riser and outflow structures are installed ensure the top invert of the overflow weir is constructed level at the design elevation.

Step 8: **Construct the Embankment and any Internal Berms.** These features must be installed in 8 to 12-inch lifts and compact the lifts with appropriate equipment.

Step 9: **Excavate and Grade.** Survey to achieve the appropriate elevation and designed contours for the bottom and side slopes of the dry pond.

Step 10: **Construct the Emergency Spillway.** The emergency spillway must be constructed in cut or structurally stabilized soils.

Step 11: **Install Outlet Pipes**. The installation of outlet pipes must include a downstream rip-rap protection apron.

Step 12: **Stabilize Exposed Soils.** All areas above the normal pool elevation should be permanently stabilized by hydroseeding or seeding over straw.

Dry Pond Construction Supervision. Ongoing construction supervision is recommended to ensure that stormwater ponds are properly constructed. Supervision/inspection is recommended during the following stages of construction:

- Preconstruction meeting
- Initial site preparation including the installation of soil erosion and sediment control measures
- Excavation/Grading (interim and final elevations)
- Installation of the embankment, the riser/primary spillway, and the outlet structure
- Implementation of the pondscaping plan and vegetative stabilization
- Final inspection (develop a punch list for facility acceptance)

DDOE's construction phase inspection checklist for storage practices and the Stormwater Facility Leak Test form can be found in Appendix K.

If the dry pond has a permanent pool, then to facilitate maintenance the contractor should measure the actual constructed dry pond depth at three areas within the permanent pool (forebay, mid-pond and at the riser), and they should mark and geo-reference them on an as-built drawing. This simple data set will enable maintenance inspectors to determine pond sediment deposition rates in order to schedule sediment cleanouts.

3.12.7 Storage Maintenance Criteria

Typical maintenance activities for storage practices are outlined in Table 3.50. Maintenance requirements for underground storage facilities will generally require quarterly visual inspections from the manhole access points by a qualified professional to verify that there is no standing water or excessive sediment buildup. Entry into the system for a full inspection of the system components (pipe or vault joints, general structural soundness, etc.) should be conducted annually. Confined space entry credentials are typically required for this inspection.

Table 3.50 Typical Maintenance Activities for Storage Practices

Schedule	Maintenance Activity
As needed	▪ Water dry pond side slopes to promote vegetation growth and survival
Quarterly	▪ Remove sediment and oil/grease from inlets, pretreatment devices, flow diversion structures, storage practices and overflow structures. ▪ Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. ▪ Ensure that the contributing drainage area is stabilized. Perform spot-reseeding where needed. ▪ Repair undercut and eroded areas at inflow and outflow structures.
Annual inspection	▪ Measure sediment accumulation levels in forebay. Remove sediment when 50% of the forebay capacity has been lost. ▪ Inspect the condition of stormwater inlets for material damage, erosion or undercutting. Repair as necessary. ▪ Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine pond embankment integrity. ▪ Inspect outfall channels 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 debris or woody vegetation, and check to see whether valves, manholes and locks can be opened and operated. ▪ Inspect internal and external side slopes of dry ponds for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately. ▪ Monitor the growth of wetlands, trees and shrubs planted in dry ponds. Remove invasive species and replant vegetation where necessary to ensure dense coverage.

Maintenance of storage practices is driven by annual inspections that evaluate the condition and performance of the storage practice. Based on inspection results, specific maintenance tasks will be triggered.

DDOE's maintenance inspection checklists for extended detention ponds and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.12.8 Storage Volume Compliance Calculations

Storage practices receive no retention value and not an accepted total suspended solids (TSS) treatment practice for the amount of storage volume (Sv) provided by the practice (Table 3.51). These practices should be used only for control of larger storm events.

Table 3.51 Storage Retention Value and Pollutant Removal

Retention Value	= 0
Accepted TSS Treatment Practice	No

3.12.9 References

Cappiella, K., Schueler, T., and T. Wright. 2005. Urban Watershed Forestry Manual. Part 1: Methods for Increasing Forest Cover in a Watershed. NA-TP-04-05. USDA Forest Service, Northeastern Area State and Private Forestry. Newtown Square, PA.

City of Austin. 1988. Design Guidelines for Water Quality Control Basins. City of Austin Environmental and Conservation Services Department, Environmental Resources Management Division. Austin, TX.

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.

Virginia DCR Stormwater Design Specification No. 15: Extended Detention (ED) Pond Version 1.8. 2010.

3.13 Proprietary Practices

Definition. Proprietary practices are manufactured stormwater treatment practices that utilize settling, filtration, absorptive/adsorptive materials, vortex separation, vegetative components, and/or other appropriate technology to manage the impacts stormwater runoff

Proprietary practices may be used to achieve treatment compliance, provided they have been approved by the District and meet the performance criteria outlined in this specification. Historically, proprietary practices do not provide retention volume. Proprietary practices will not be valued for retention volume unless the practice can demonstrate the occurrence of retention processes.

3.13.1 Proprietary Practice Feasibility Criteria

Individual proprietary practices will have different site constraints and limitations. Manufacturer's specifications should be consulted to ensure that proprietary practices are feasible for application on a site-by-site basis.

3.13.2 Proprietary Practice Conveyance Criteria

All proprietary practices must be designed to safely overflow or bypass flows from larger storm events to downstream drainage systems. The overflow associated with the 2-year and 15-year design storms must be controlled so that velocities are non-erosive at the outlet point (i.e., to prevent downstream erosion).

Manufactured treatment devices may be constructed on-line or off-line. On-line systems receive upstream runoff from all storms, providing runoff treatment for the stormwater quality design storm and conveying the runoff from larger storms through an overflow. In off-line devices, most or all of the runoff from storms larger than the stormwater quality design storm bypass the device through an upstream diversion or other mechanism.

3.13.3 Proprietary Practice Pretreatment Criteria

Individual proprietary practices may require pretreatment, or may be appropriate for use as pretreatment devices. Manufacturer's specifications should be consulted to determine the device-specific pretreatment requirements.

3.13.4 Proprietary Practice Design Criteria

The basic design parameters for a proprietary practice will depend on the techniques it employs to control stormwater runoff and remove particulate and dissolved pollutants from runoff. In general, the design of devices that treat runoff with no significant storage and flow rate attenuation must be based upon the peak design flow rate. However, devices that do provide storage and flow rate attenuation must be based, at a minimum, on the design storm runoff volume and, in some instances, on a routing of the design runoff hydrograph. Hydrologic design is discussed further in Appendix H.

Appendix S includes details of the verification process and the required data submittals for determination of proprietary practice performance.

3.13.5 Proprietary Practice Landscaping Criteria

Proprietary devices may or may not require landscaping considerations. Manufacturer's specifications should be consulted to determine any landscaping requirements for the device.

3.13.6 Proprietary Practice Construction Sequence

The construction and installation of individual proprietary practices will vary based on the specific proprietary practice. Manufacturer's specifications should be consulted to determine the device specific construction sequencing requirements. DDOE's construction inspection checklist for generic structural BMPs can be found in Appendix K.

3.13.7 Proprietary Practice Maintenance Criteria

In order to ensure effective and long-term performance of a proprietary practice, regular maintenance tasks and inspections are required.

All proprietary practices should be inspected by a qualified professional and maintained in accordance with the manufacturer's instructions and/or recommendations and any maintenance requirements associated with the device's verification by DDOE.

DDOE's maintenance inspection checklist for generic structural BMPs and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.13.8 Proprietary Practice Stormwater Compliance Calculations

Proprietary practices receive retention value when explicitly approved by the District. Pollutant removal (TSS EMC reduction) may be awarded for specific practices provided that they meet the performance criteria outlined in Section 3.13.4. Proprietary Practice Design Criteria.

3.14 Tree Planting and Preservation

Definition. Existing trees can be preserved or new trees can be planted to reduce stormwater runoff.

Tree canopy can intercept a significant amount of rainfall before it becomes runoff, particularly if the tree canopy covers impervious surface, such as in the case of street trees. Through the processes of evapotranspiration and nutrient uptake, trees located on a development site have the capacity to reduce stormwater runoff volumes and improve water quality. Further, through root growth, trees can improve the infiltration capacity of the soils in which they grow.

Both tree planting and tree preservation can contribute to stormwater management on a site.

3.14.1 Preserving Existing Trees During Construction

The preferred method for increasing tree cover at a development site is to preserve existing trees during construction, particularly where mature trees are present. Existing trees are preserved during construction through a four-step process:

Step 1: Inventory existing trees.

Step 2: Identify trees to preserve.

Step 3: Protect trees and soil during construction.

Step 4: Protect trees after construction.

Inventory Existing Trees. A licensed forester or arborist must conduct an inventory of existing trees and forested areas at the development site before any site design, clearing, or construction takes place, as specified by the Urban Forestry Administration (UFA).

The inventory must include a survey of existing trees and determine their size, species, condition, and ecological value. Locations of trees and forest stands must be recorded.

Identify Trees to Preserve. From the tree inventory, individual trees can be identified for preservation and protection during site development. In order to receive retention value, preserved trees must be a species with an average mature spread of at least 35 feet. Additional selection criteria may include tree species, size, condition, and location (Table 3.52).

Table 3.52 Selecting Priority Trees and Forests for Preservation

Selection Criteria for Tree Preservation	Examples of Priority Tree and Forests to Conserve
Species	▪ Rare, threatened, or endangered species ▪ Specimen trees ▪ High quality tree species (e.g., white oaks and sycamores because they are structurally strong and live longer than trees such as silver maple and cottonwood) ▪ Species that are tolerant of specific site conditions and soils
Size	▪ Trees over a specified diameter at breast height (d.b.h.) or other size measurement ▪ Trees designated as national, state, or local champions ▪ Contiguous forest stands of a specified minimum area
Condition	▪ Healthy trees that are structurally sound ▪ High quality forest stands with high forest structural diversity
Location	▪ Trees located where they will provide direct benefits at the site (e.g., shading, privacy, windbreak, buffer from adjacent land use) ▪ Forest stands that are connected to off-site forests that create wildlife habitat and corridors ▪ Trees located in protected natural areas such as floodplains, stream buffers, wetlands, erodible soils, critical habitat areas, and steep slopes. ▪ Forest stands that are connected to off-site non-forested natural areas or protected land (e.g., has potential to provide wildlife habitat)

Trees selected for preservation and protection must be clearly marked both on construction drawings and at the actual site. Flagging or fencing are typically used to protect trees at the construction site. Areas of trees to preserve should be marked on the site map and walked during preconstruction meetings.

Protect Trees and Soil During Construction. Physical barriers must be properly installed around the Critical Root Zone (CRZ) of trees to be preserved. The CRZ shall be determined by a licensed forester or ISA certified arborist, and in general includes a circular area with a radius (in feet) equal to 15 times the diameter of the trunk (in inches). The barriers must be maintained and enforced throughout the construction process. Tree protection barriers include highly visible, well-anchored temporary protection devices, such as 4-foot fencing, blaze orange plastic mesh fencing, or snow fencing (Greenfeld and others, 1991).

All protection devices must remain in place throughout construction

When excavation is proposed immediately adjacent to the CRZ, roots must first be pruned at the edge of the excavation with a trenching machine, vibratory knife or rock saw to a depth of 18 inches.

Protect Trees After Construction. Maintenance covenants, as described below, are required to ensure that preserved trees are protected.

3.14.2 Planting Trees

Considerations at Development Sites. New development sites provide many opportunities to plant new trees. Planting trees at development sites is done in three steps:

Step 1: Select tree species.

Step 2: Evaluate and improve planting sites.

Step 3: Plant and maintain trees.

Tree Species. In order to receive retention value, the tree species planted must have an average mature spread of at least 35 feet. Trees to be planted must be container grown, or ball and burlap, and have a minimum caliper size of 1.5 inches. Bare root trees or seedlings do not qualify for retention value.

Planting Sites. Ideal planting sites within a development are those that create interception opportunities around impervious surfaces. These include areas along pathways, roads, islands and median strips, and parking lot interiors and perimeters. Other areas of a development site may benefit from planting trees (including stream valleys and floodplains, areas adjacent to existing forest, steep slopes, and portions of the site where trees would provide buffers, screening, noise reduction, or shading).

It is important to evaluate and record the conditions, such as soil type, soil pH, soil compaction, and the hydrology of proposed planting sites to ensure they are suitable for planting. These evaluations provide a basis for species selection and determination of the need for any special site preparation techniques.

A minimum of 1,500 cubic feet of rootable soil volume must be provided per tree. In planting arrangements that allow for shared rooting space amongst multiple trees, a minimum of 1,000 cubic feet of rootable soil volume must be provided for each tree. Rootable soil volume must be within 3 feet of the surface.

Site characteristics determine what tree species will flourish there and whether any of the conditions, such as soils, can be improved through the addition of compost or other amendments. Table 3.53 presents methods for addressing common constraints to urban tree planting.

Table 3.53 Methods for Addressing Urban Planting Constraints

Potential Impact	Potential Resolution
Limited Soil Volume	▪ Provide 1,500 cubic feet of rootable soil volume per tree ▪ Use planting arrangements that allow shared rooting space. A minimum of 1.000 cubic feet of rootable soil volume must be provided for each tree in shared rooting space arrangements. ▪ Provide 1500 cubic feet of rootable soil volume per tree (this soil must be within 3 feet of the surface)
Poor Soil Quality	▪ Test soil and perform appropriate restoration ▪ Select species tolerant of soil pH, compaction, drainage, etc. ▪ Replace very poor soils if necessary
Air Pollution	Select species tolerant of air pollutants
Damage from Lawnmowers	Use mulch to protect trees
Damage from Vandalism	▪ Use tree cages or benches to protect trees ▪ Select species with inconspicuous bark or thorns ▪ Install lighting nearby to discourage vandalism
Damage from Vehicles	Provide adequate setbacks between vehicle parking stalls and trees
Damage from animals such as deer, rodents, rabbits, and other herbivores	Use protective fencing or chemical retardants
Exposure to pollutants in stormwater and snowmelt runoff	Select species that are tolerant of specific pollutants, such as salt and metals
Soil moisture extremes	▪ Select species that are tolerant of inundation or drought ▪ Install underdrains if necessary ▪ Select appropriate backfill soil and mix thoroughly with site soil ▪ Improve soil drainage with amendments and tillage if needed
Increased temperature	Select drought tolerant species
Increased wind	Select drought tolerant species
Abundant populations of invasive species	▪ Control invasive species prior to planting ▪ Continually monitor for and remove invasive species
Conflict with infrastructure	▪ Design the site to keep trees and infrastructure separate ▪ Provide appropriate setbacks from infrastructure ▪ Select appropriate species for planting near infrastructure ▪ Use alternative materials to reduce conflict
Disease or insect infestation	Select resistant species

Planting trees at development sites requires prudent species selection, a maintenance plan, and careful planning to avoid impacts from nearby infrastructure, runoff, vehicles or other urban elements.

Trees Along Streets and in Parking Lots. When considering a location for planting clear lines of sight must be provided, as well as safe travel surfaces, and overhead clearance for pedestrians and vehicles. Also, ensure enough future soil volume for healthy tree growth. At least two cubic feet of useable soil per square foot of average mature tree canopy is required. (Useable soil must be uncompacted, and may not be covered by impervious material). Having at least a 6-foot wide planting strip or locating sidewalks between the trees and street allows more rooting space for trees in adjacent property.

Select tree species that are drought tolerant, can grow in poor or compacted soils, and are tolerant to typical urban pollutants (oil and grease, metals, and chlorides). Additionally, select species that do not produce excessive fruits, nuts, or leaf litter, that have fall color, spring flowers or some other aesthetic benefit, and can be limbed up to 6 feet to provide pedestrian and vehicle traffic underneath. The District Department of Transportation, Urban Forestry Administration (DDOT UFA) provides guidance on preferred street tree species based on neighborhoods.

Planting Techniques. Prepare a hole no deeper than the root ball or mass but two to three times wider than the spread of the root ball or mass. The majority of the roots on a newly planted tree will develop in the top 12 inches of soil and spread out laterally. There are some additional considerations depending on the type of plant material being used (Table 3.54).

Table 3.54 Tree Planting Techniques

Plant Material	Planting Technique	Planting Season
Container grown	Hand plant or use mechanical planting tools (e.g., auger)	Spring or fall, summer if irrigated
Balled and burlapped	Use backhoe (or other specialized equipment) or hand plant	Spring or fall

Sources: Palone and Todd (1998), WSAHGP (2002)

One of the most important planting guidelines is too make sure the tree is not planted too deeply. The root collar, the lowest few inches of trunk just above its junction with the roots (often indicated by a flare), should be exposed (Flott, 2004). Trees planted too deeply have buried root collars, and are weakened, stressed, and predisposed to pests and disease (Flott, 2004). Trees planted too deeply can also form adventitious roots near the soil surface in an attempt to compensate for the lack of oxygen available to buried roots. Adventitious roots are not usually large enough to provide support for a large tree and may eventually lead to collapse (Flott, 2004). ISA (2005) provides additional guidance on how to avoid planting too deeply. It is generally better to plant the tree a little high, that is, with the base of the trunk flare 2 to 3 inches above the soil, rather than at or below the original growing level (ISA, 2003b).

Proper handling during planting is essential to avoid prolonged transplant shock and ensure a healthy future for new trees and shrubs. Trees should always be handled by the root ball or container, never by the trunk. Specifications for planting a tree are illustrated in Figure 3.42. Trees must be watered well after planting.

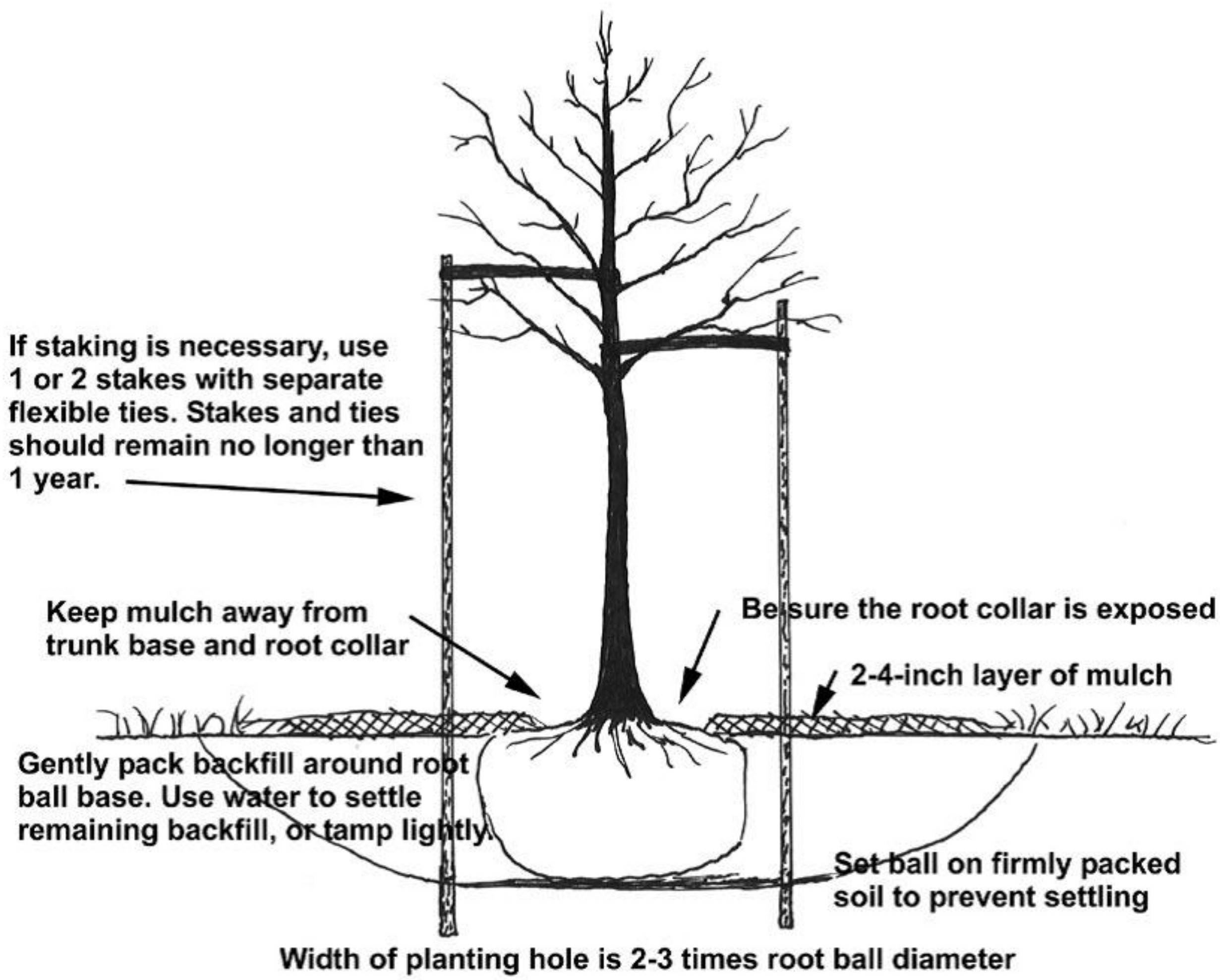


Figure 3.42 Tree planting guidelines. (Adapted from Flott, 2004 and ISA, 2003b).

Steep slopes require additional measures to ensure planting success and reduce erosion, especially if the slope receives stormwater runoff from upland land uses. Depending on the steepness of the slope and the runoff volume, rill or gully erosion may occur on these slopes, requiring a twofold approach: controlling the stormwater and stabilizing the slope.

Erosion control blankets are recommended to temporarily stabilize soil on slopes until vegetation is established (Caraco, 2000; Morrow and others, 2002). Erosion control fabrics come in a variety of weights and types, and should be combined with vegetation establishment such as seeding. Other options for stabilizing slopes include applying compost or bark mulch, plastic sheeting, or sodding (Caraco, 2000).

Trees will add stability to slopes because of their deep roots, provided they are not planted by digging rows of pits across a slope (Morrow and others, 2002). Required maintenance will include mowing (if slopes are not too steep), and establishing cover on bare or eroded areas.

Planting methods for slopes steeper than 3:1 (1 foot vertical change for every 3 horizontal feet) involve creating a level planting space on the slope (see Figure 3.43). A terrace can be dug into the slope in the shape of a step. The existing slope can be cut and the excavated soil can be used as fill. A low soil berm (or rock berm) can be formed at the front edge of each step or terrace to slow the flow of water. Trees can also be planted in clusters on slopes (using the above method) to limit potential for desiccation. Staggering tree placement and mulching will prevent water from running straight downhill.

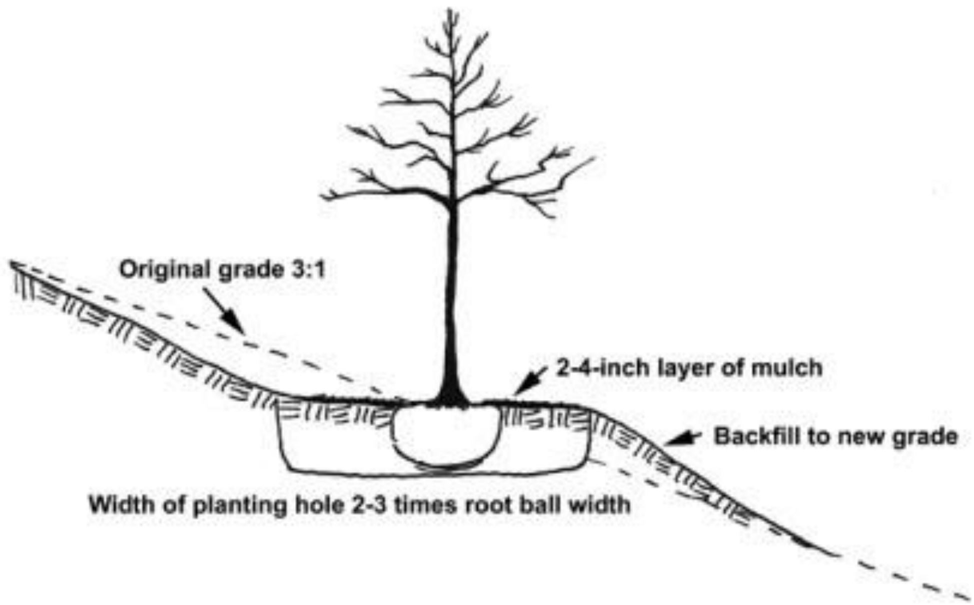


Figure 3.43 The specifications for planting on a steep slope, require creating a level planting surface.

Post-Planting Tree Protection. Once the tree has been properly planted, 2 to 4 inches of organic mulch must be spread over the soil surface out to the drip line of the tree. If planting a cluster of trees, mulch the entire planting area. Slow-decomposing organic mulches, such as shredded bark, compost, leaf mulch, or wood chips provide many added benefits for trees. Mulch that contains a combination of chips, leaves, bark, and twigs is ideal for reforestation sites. (ACB, 2000; ISA, 2003a). Grass clippings and sawdust are not recommended as mulches because they decompose rapidly and require frequent application, resulting in reduced benefits.

For well-drained sites up to 4 inches of mulch may be applied, and for poorly drained sites a thinner layer of mulch should be applied. Mulch should never be more than 4 inches deep or applied right next to the tree trunk; however, a common sight in many landscaped areas is the "mulch volcano". This over-mulching technique can cause oxygen and moisture-level problems, and decay of the living bark at the base of the tree. A mulch-free area, 2- to 3-inches wide at the base of the tree, must be provided to avoid moist bark conditions and prevent decay (ISA, 2003a).

Studies have shown that trees will establish more quickly and develop stronger trunk and root systems if they are not staked at the time of planting (ISA, 2003b). Staking for support may be necessary only for top-heavy trees or at sites where vandalism or windy exposure are a concern (Buckstrup and Bassuk, 2003; Doherty and others, 2003; ISA, 2003b).

If staking is necessary for support, two stakes used in conjunction with a wide flexible tie material will hold the tree upright, provide flexibility, and minimize injury to the trunk. To prevent damage to the root ball, stakes should be placed in undisturbed soil beyond the outer edges of the root ball. Perhaps the most important part of staking is its removal. Over time, guy wires (or other tie material) can cut into the growing trunk bark and interfere with the movement of water and nutrients within the tree. Staking material should be removed within 1 year of planting (Doherty and others, 2003).

3.14.3 Tree Inspection Criteria

An initial inspection by a qualified professional must be done to ensure the tree has been planted, watered, and protected correctly with locations flagged if appropriate. For newly planted trees, transplant shock is common and causes stress on a new tree. For this reason, newly planted trees must be inspected more frequently than established trees. The time it takes for a tree to become established varies with the size at planting, species, stock, and site conditions, but generally, trees should be inspected every few months during the first 3 years after planting, to identify problems and implement repairs or modify maintenance strategies (WSAHGP, 2002).

After the first 3 years, annual inspections are sufficient to check for problems. Trees must also be inspected after major storm events for any damage that may have occurred. The inspection should take only a few minutes per tree, but prompt action on any problems encountered results in healthier, stronger trees. Inspections should include an assessment of overall tree health, an assessment of survival rate of the species planted, cause of mortality, if maintenance is required, insect or disease problems, tree protection adjustment, and weed control condition.

DDOE’s construction phase inspection checklist for tree planting and preservation can be found in Appendix K.

3.14.4 Tree Maintenance Criteria

Water newly planted trees regularly (at least once a week) during the first growing season. Water trees less frequently (about once a month) during the next two growing seasons. After three growing seasons, water trees only during drought. The exact watering frequency will vary for each tree and site.

A general horticultural rule of thumb is that trees need 1 inch of rainfall per week during the growing season (Petit and others, 1995). This means new trees need a minimum of 25 gallons of water a week to stay alive (http://caseytrees.org/get-involved/water/). Water trees deeply and slowly near the roots. Light, frequent watering of the entire plant can actually encourage roots to grow at the surface. Soaker hoses and drip irrigation work best for deep watering of trees. It is recommend that slow leak watering bags or tree buckets are installed to make watering easier and more effective. Continue watering until mid-fall, tapering off during lower temperatures.

Pruning is usually not needed for newly planted trees but may be beneficial for tree structure. If necessary, prune only dead, diseased, broken or crossing branches at planting (Doherty and others, 2003; Trowbridge and Bassuk, 2004). As the tree grows, lower branches may be pruned to provide clearance above the ground, or to remove dead or damaged limbs.

DDOE's maintenance inspection checklist for tree planting and preservation and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A maintenance covenant is required for all stormwater management practices. The covenant specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The covenant is attached to the deed of the property (see standard form, variations exist for scenarios where stormwater crosses property lines). A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. There may be a maintenance schedule on the drawings themselves or the plans may refer to the maintenance schedule (Exhibit C in the covenant).

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.14.5 Tree Stormwater Compliance Calculations

Trees receive retention value but they are not accepted total suspended solids (TSS) treatment practices.

To ensure appropriate stormwater benefits associated with proposed tree preservation or planting, all trees receiving retention value must be properly maintained until redevelopment of the area occurs. If trees die they must be replaced with a similar tree no longer than 6 months from time of death in an appropriate location.

Preserved trees that meet the requirements described above receive a retention value of 20 cubic feet each. Planted trees that meet the requirements described above receive a retention value of 10 cubic feet each.

Note: Trees planted as part of another BMP, such as a bioretention area, also receive the 10 cubic foot retention value. Retention values are shown in Tables 3.55 and 3.56 below.

Table 3.55 Preserved Tree Retention Value and Pollutant Removal

Retention Value	= 20*cf* (150 gallons)
Accepted TSS Treatment Practice	No

Table 3.56 Planted Tree Retention Value and Pollutant Removal

Retention Value	= 10*cf* (75 gallons)
Accepted TSS Treatment Practice	No

Trees also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the retention value from the total runoff volume for the 2-year, 15-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a Reduced Natural Resource Conservation Service (NRCS) Curve Number for the site or drainage area. The Reduced Curve Number can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

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Chapter 4 Selecting and Locating the Most Effective Stormwater Best Management Practice System

4.1 Choosing Stormwater Management Best Practices (BMPs)

This chapter outlines a general process for selecting appropriate BMPs at a development site. Guidelines are presented for choosing which BMPs can meet the retention and treatment volume targets for design storms and which BMPs are most feasible when various site constraints are present.

This chapter represents guidelines, not rules, to determine the most appropriate BMP for a site. It is important to note that certain BMP design modifications or specific site characteristics may allow for a particular BMP to become better suited at a particular location. Several of these design modifications are noted in the following tables and are described in more detail in the individual BMP specifications (see Chapter 3).

The following questions organize a framework for decision making:

- **Regulatory Criteria**

  Can the BMP meet all stormwater sizing criteria at the site or are a combination of BMPs needed?

- **Land Use Factors**

  Which practices are best suited for the proposed land use at this site?

- **Physical Feasibility Factors**

  Are there any physical constraints at the project site that may restrict or preclude the use of a particular BMP?

- **Community and Environmental Factors**

  Do the remaining BMPs have any important community or environmental benefits or drawbacks that might influence the selection process?

- **Location and Permitting Considerations**

  What environmental features must be avoided or considered when locating the BMP system at a site to fully comply with District and federal regulations?

4.2 Regulatory Compliance

Table 4.1 summarizes the capability of each BMP to meet the stormwater management sizing criteria outlined in Chapter 2. Designers can use Table 4.1 to screen BMP options to determine whether a particular BMP can meet the SWRv storage, peak discharge (Qp_2, Qp_{15}, and Q_f), and pollutant removal requirements. Finding that a particular BMP cannot meet a requirement does not necessarily mean that it should be eliminated from consideration. This screening process can reduce BMP options to a manageable number and determine whether a single BMP or a group of BMPs will be needed to meet stormwater sizing criteria at the site.

The following are key considerations for compliance:

- **Stormwater Retention Volume (SWRv) Storage.** A single BMP may not be capable of meeting the SWRv requirement. This column can assist in identifying supplemental practices.
- **Quantity Control (Qp_2, Qp_{15}, or Q_f).** These columns show whether a BMP can typically meet the peak discharge requirements.
- **Pollutant Removal.** This column examines the capability of each BMP option to remove total suspended solids (TSS) from stormwater runoff.

Note: Table 4.1 should be used as a guide for how practices typically perform. Individual designs may be sized or designed with greater or lesser capabilities than are indicated in the table.

Table 4.1 BMP Selection Based on Regulatory Criteria

<table>
<tr><th>Code</th><th>BMP</th><th>SWRv Storage</th><th>Qp_2/Qp_{15} Control</th><th>Q_f Control</th><th>TSS Removal</th></tr>
<tr><td>G-1</td><td>Extensive Green Roof</td><td rowspan="2">●</td><td>⦿</td><td rowspan="2">☒</td><td rowspan="2">N/A</td></tr>
<tr><td>G-2</td><td>Intensive Green Roof</td><td>⦿</td></tr>
<tr><td>R-1</td><td>Rainwater Harvesting</td><td>⦿</td><td>⦿</td><td>☒</td><td>N/A</td></tr>
<tr><td>D-1</td><td>Simple Disconnection to a Pervious Area</td><td rowspan="3">⦿</td><td rowspan="3">☒</td><td rowspan="3">☒</td><td rowspan="3">NO</td></tr>
<tr><td>D-2</td><td>Simple Disconnection to a Conservation Area</td></tr>
<tr><td>D-3</td><td>Simple Disconnection to a Soil Compost Amended Filter Path</td></tr>
<tr><td>P-1</td><td>Porous Asphalt</td><td rowspan="3">●</td><td rowspan="3">⦿</td><td rowspan="3">☒</td><td rowspan="3">N/A or Yes*</td></tr>
<tr><td>P-2</td><td>Pervious Concrete</td></tr>
<tr><td>P-3</td><td>Permeable Pavers</td></tr>
<tr><td>B-1</td><td>Traditional Bioretention</td><td rowspan="5">●</td><td>⦿</td><td rowspan="5">☒</td><td rowspan="5">N/A or Yes*</td></tr>
<tr><td>B-2</td><td>Streetscape Bioretention</td><td>⦿</td></tr>
<tr><td>B-3</td><td>Expanded Tree Pits</td><td>⦿</td></tr>
<tr><td>B-4</td><td>Stormwater Planters</td><td>⦿</td></tr>
<tr><td>B-5</td><td>Residential Rain Gardens</td><td>⦿</td></tr>
<tr><td>F-1</td><td>Surface Sand Filter</td><td rowspan="3">☒</td><td rowspan="3">☒</td><td rowspan="3">☒</td><td rowspan="3">Yes</td></tr>
<tr><td>F-2</td><td>1-Chamber Underground Sand Filter</td></tr>
<tr><td>F-3</td><td>3-Chamber Underground Sand Filter</td></tr>
</table>

Code	BMP	SWRv Storage	Qp_2/Qp_{15} Control	Q_f Control	TSS Removal
F-4	Perimeter Sand Filter				
I-1	Infiltration Trench	●	⦿	☒	N/A
I-2	Infiltration Basin				
O-1	Grass Channels	⦿	☒	☒	No
O-2	Dry Swale	●			Yes
O-3	Wet Swale	☒			Yes
P-1	Micropool Extended Detention Pond	☒	●	●	Yes
P-2	Wet Pond				
P-3	Wet Extended Detention Pond				
W-1	Shallow Wetland	☒	●	●	Yes
W-2	Extended Detention Shallow Wetland				
S-1	Underground Detention	☒	●	●	No
S-2	Dry Extended Detention Pond				
PP-1	Proprietary Practice	☒	☒	☒	Yes
TP-1	Tree Preservation	⦿	☒	☒	No
TP-2	Tree Planting				

● = Yes; ⦿ = Partial; ☒ = Minor or No Benefit
* Depends upon design type.

4.3 Land Use Factors

Designers can use Table 4.2 to evaluate BMPs that are best suited to a particular land use, including highly urbanized areas.

The following are key considerations for land use factors:

- **Residential.** This column identifies the best treatment options in medium to high density residential developments.
- **Commercial Development.** This column identifies practices that are suitable for new commercial development.
- **Roads and Highways.** This column identifies the best practices to treat runoff from major roadway and highway systems.
- **Hotspot Land Uses.** This column examines the capability of BMPs to treat runoff from designated hotspots. BMPs that receive hotspot runoff may have design restrictions, as noted.

Table 4.2 BMP Selection Based on Land Use Screening Factors

Code	BMP	Residential	Commercial	Roads and Highways	Hotspots
G-1	Extensive Green Roof	⦿	●	☒	☒
G-2	Intensive Green Roof				
R-1	Rainwater Harvesting	●	●	☒	☒
D-1	Simple Disconnection to a Pervious Area	●	●	⦿	☒
D-2	Simple Disconnection to a Conservation Area				
D-3	Simple Disconnection to a Soil Compost Amended Filter Path				
P-1	Porous Asphalt	⦿	●	①	☒
P-2	Pervious Concrete				
P-3	Permeable Pavers				
B-1	Traditional Bioretention	●	●	⦿	②
B-2	Streetscape Bioretention		●	●	
B-3	Expanded Tree Pits		●	●	
B-4	Stormwater Planters		●	☒	
B-5	Residential Rain Gardens		☒	☒	
F-1	Surface Sand Filter	☒	●	●	●
F-2	1-Chamber Underground Sand Filter			⦿	
F-3	3-Chamber Underground Sand Filter			⦿	
F-4	Perimeter Sand Filter			⦿	
I-1	Infiltration Trench	⦿	●	⦿	☒
I-2	Infiltration Basin				
O-1	Grass Channel	●	●	●	②
O-2	Dry Swale				
O-3	Wet Swale				
P-1	Micropool Extended Detention Pond	●	⦿	⦿	③
P-2	Wet Pond				
P-3	Wet Extended Detention Pond				
W-1	Shallow Wetland	●	●	⦿	③
W-2	Extended Detention Shallow Wetland				
S-1	Underground Detention	☒	●	●	☒
S-2	Dry Pond	●	●	⦿	
PP-1	Proprietary Practice	●	●	●	●
TP-1	Tree Preservation	●	●	●	●
TP-2	Tree Planting				

● = Yes; ⦿ = Maybe; ☒ = No
①- Recommended for low volume roads or parking lanes
②-Yes, only if designed with an impermeable liner
③-May require pond liner to reduce the risk of GW contamination

4.4 Physical Feasibility Factors

Typically, the designer narrows the BMP selection list based on regulatory goals and land use constraints before considering physical feasibility factors. Table 4.3 identifies the typical physical conditions needed for each type of BMP. Designers can use Table 4.3 to screen BMP options to determine whether the soils, water table, drainage area, slope, or head conditions present at a particular development site might limit the use of a BMP. These factors are intended as guidelines rather than requirements.

The following are key considerations for physical feasibility:

- **Underlying Soils.** The designer should use NRCS hydrologic soils maps to generally identify expected soils and their locations at the site. More detailed geotechnical tests are required during BMP design to evaluate infiltration feasibility and related design parameters. Once the infiltration rate at a site has been measured, use this column and Table 4.4 to identify recommended design criteria for proposed BMPs that have an infiltration option.
- **Distance to Water Table.** Measure the depth of the groundwater and estimate the depth of the seasonally high water table (see Appendix O). Use this column as an aid to determine recommended BMP sizing.
- **Contributing Drainage Area.** Delineate the contributing drainage area to the proposed BMP, and use this column as an aid to determine the appropriate sizing factor. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, some leeway is permitted. Likewise, the minimum drainage areas indicated for ponds and wetlands should not be considered inflexible limits, and may be increased or decreased depending on water availability (baseflow or groundwater) or the mechanisms employed to prevent clogging or ensure an impermeable pond bottom.
- **Practice Surface Slope.** Evaluate the site topography. Determine the potential for cut and fill operations. Use this column as an aid to evaluate BMP surface slope restrictions. Specifically, the slope restrictions refer to how flat the area where the practice is installed must be.
- **Head.** To evaluate BMP options, determine the elevation of the discharge point, and use this column as an aid to estimate the elevation difference needed from the inflow to the outflow to allow for gravity operation.

Table 4.3 BMP Selection Based on Physical Feasibility Screening Factors

Code	BMP List	Underlying Soils	Distance to Water Table (ft)	Contributing Drainage Area (ac)	Practice Surface Slope (%)	Head (ft)
G-1	Extensive Green Roof	N/A	N/A	green roof surface area + 25%	1–2[a]	N/A
G-2	Intensive Green Roof					
R-1	Rainwater Harvesting	N/A	N/A	no limit	N/A	N/A
D-1	Simple Disconnection to a Pervious Area	all soils	N/A	< 1,000 ft^2 per rooftop downspout[b]	< 5	N/A
D-2	Simple disconnection to a conservation area				< 6	
D-3	Simple Disconnection to a Soil Compost Amended Filter Path				< 5	
P-1	Porous Asphalt	all soils (i < 0.5 in./hr may require underdrains)	2	2–5 × practice surface area	< 5	2–4
P-2	Pervious Concrete					
P-3	Permeable Pavers					
B-1	Traditional Bioretention	all soils (i < 0.5 in./hr may require underdrains)	2	< 2.5	< 1	4–5
B-2	Streetscape Bioretention			< 1		
B-3	Expanded Tree Pits			< 1		
B-4	Stormwater Planters			< 1		
B-5	Residential Rain Gardens			< 1		
F-1	Surface Sand Filter	all soils	2	< 5	N/A	5
F-2	1-Chamber Underground Sand Filter			< 10,000 ft^2		5–10
F-3	3-Chamber Underground Sand Filter			< 2		5–10
F-4	Perimeter Sand Filter			< 2		2–3
I-1	Infiltration Trench	i > 0.5 in/hr is preferred	2	< 2	< 1	2
I-2	Infiltration Basin			< 5		
O-1	Grass Channel	all soils	2	< 2.5	< 4	1
O-2	Dry Swale	all soils (i < 0.5 in./hr may require underdrains)	2			3–5
O-3	Wet Swale	i < 0.5 in./hr	intersect WT			1
P-1	Micropool Extended Detention Pond	soils i > 0.5 in./hr may require pond liner	N/A	10–25	< 1	6–8
P-2	Wet Pond		N/A	10–25		6–8
P-3	Wet Extended Detention Pond		N/A	10–25		6–8
W-1	Shallow Wetland	soils i > 0.5 in./hr may require pond liner	N/A	> 25[e]	< 1	2–4
W-2	Extended Detention Shallow Wetland		N/A			
S-1	Underground Detention	all soils	no restrictions	no restrictions	< 1	> 5
S-2	Dry Extended Detention Pond		2	> 10[d]	< 1	6–8

Code	BMP List	Underlying Soils	Distance to Water Table (ft)	Contributing Drainage Area (ac)	Practice Surface Slope (%)	Head (ft)
PP-1	Proprietary Practice	All soils	2	design dependent	N/A	2–5
TP-1	Tree Preservation	All soils	N/A	N/A	N/A	N/A
TP-2	Tree Planting		N/A	N/A		

Notes: i= infiltration rate or permeability, WT= water table, N/A= not applicable
a Green roof slope can be up to 25% if baffles are used to ensure detention of the design storm
b For impervious areas other than rooftop, the longest contributing impervious area flow path cannot exceed 75 feet.
c The required head for bioretention areas can be reduced in small applications or when an upturned or elevated underdrain design is used
d No limit but practical drainage area limitations may exist due to minimum orifice size (e.g., 1-inch diameter with internal orifice)
e CDA can be smaller if the practice intersects the water table

Table 4.4 Selection of Infiltration BMPs Based on Measured Infiltration Rate*

Measured Infiltration Rate (in./hr)			
	Less than 0.25	**0.25 to 0.5**	**More than 0.5**
Recommended Design Solution	Use Bioretention, Dry Swale, or Permeable Pavement (likely with an underdrain). Do not use Infiltration Trench/Basin.	Use Bioretention, Dry Swale, or Permeable Pavement (likely with an underdrain). It may be beneficial to include an infiltration sump below the underdrain invert. Infiltration Trench/Basin may not be appropriate.	Use Infiltration Trench/Basin, Bioretention, Dry Swale, or Permeable Pavement without an underdrain.

*Designers must use ½ of the measured infiltration rate for design purposes, as indicated in the design equations given in Chapter 3.

4.5 Community and Environmental Factors

Designers can use Table 4.5 to compare the BMP options with regard to maintenance, habitat, community acceptance, cost, safety, space consumption, and other environmental factors. Table 4.5 employs a comparative index approach to rank the benefits of community and environmental factors as high, medium, or low.

The following are key considerations for community and environmental factors:

- **Maintenance Burden.** This column identifies the relative maintenance effort needed for each BMP option, in terms of the frequency of scheduled maintenance, chronic maintenance problems (such as clogging), and reported failure rates. All BMPs require routine inspection and maintenance (see Appendix L Maintenance Inspection Checklists).

- **Cost.** This column ranks BMPs according to their relative construction cost per cubic foot of stormwater retained, as determined from cost surveys and local experience.
- **Safety Risk.** This column provides a comparative index of the potential safety risks of each BMP option, when designed according to the performance criteria outlined in Chapter 3. The index is included to highlight the need for considerations of liability and public safety in locations, such as residential, public space, schools, and others. A comparatively higher risk BMP may require signage, fencing, or other measures needed to alert the general public or maintenance provider of a potentially harmful situation.
- **Space Required.** This column provides a comparative index of the amount of space each BMP option typically consumes at a site. It may be helpful to consider this factor at an early stage of design because many urban BMPs are constrained by availability of open land.
- **Environmental Factors.** This column assesses the range of environmental factors considered under the Green Area Ratio (GAR) process to identify the broader human and environmental beneficial intersections some BMPs provide. For instance some BMPs contribute to air quality improvements and reduce the urban heat island effect.
- **Habitat Value.** This column evaluates the ability of BMPs to provide wildlife or wetland habitat, assuming that an effort is made to landscape them appropriately. Objective criteria include size, water features, wetland features, and vegetative cover of the BMP and its buffer.
- **Other Factors.** This column indicates other considerations in BMP selection.

Table 4.5 BMP Selection Based on Community and Environmental Factors

Code	BMP List	Maintenance Burden	Cost*	Safety Risk	Space Required	Environmental Benefits	Habitat Value	Other Factors
G-1	Extensive Green Roof	L	H	L	L	H	L	Increases structural loading on building
G-2	Intensive Green Roof	M	H				M	
R-1	Rainwater Harvesting	L	M	L	L	H	L	
D-1	Simple Disconnection to a Pervious Area	L	L	L	M	M	L	
D-2	Simple Disconnection to a Conservation Area							
D-3	Simple Disconnection to a Soil Compost Amended Filter Path							
P-1	Porous Asphalt	H	H	L	L	M	L	
P-2	Pervious Concrete							
P-3	Permeable Pavers							
B-1	Traditional Bioretention	M	L	L	M	H	M	Can be used as landscaping features
B-2	Streetscape Bioretention	H	H		M		M	
B-3	Expanded Tree Pits	M	H		L		M	
B-4	Stormwater Planters	L	M		L		L	
B-5	Residential Rain Gardens	L	L		L		M	
F-1	Surface Sand Filter	M	L	L	M	L	L	Minimize concrete
F-2	1-Chamber Underground Sand Filter	H	M	M	L			Out of sight
F-3	3-Chamber Underground Sand Filter	H	H	M	L			Out of sight
F-4	Perimeter Sand Filter	M	M	L	M			Traffic bearing
I-1	Infiltration Trench	L	M	L	M	L	L	Avoid large stone
I-2	Infiltration Basin							Frequent pooling

Notes: H = High; M = Medium; L=Low
* Cost based on $ per cubic foot of stormwater treated

Code	BMP List	Maintenance Burden	Cost*	Safety Risk	Space Required	Environmental Benefits	Habitat Value	Other Factors
S-1	Underground Detention	M	H	M	L	L	L	Out of sight
S-2	Dry Pond		L		H	M		
P-1	Micropool Extended Detention Pond	M	L	M	H	M	L	Trash/debris
P-2	Wet Pond	H					H	High pond premium
P-3	Wet Extended Detention Pond	H					H	
W-1	Shallow Wetland	M	M	L	H	H	H	
W-2	Extended Detention Shallow Wetland			M				Limit ED depth
O-1	Grass Channel	M	L	L	M	M	L	
O-2	Dry Swale	H	M				L	
O-3	Wet Swale	H	M				M	Possible mosquitoes

Notes: H = High; M = Medium; L=Low
* Cost based on $ per cubic foot of stormwater treated

4.6 Location and Permitting Considerations

In this step, the designer follows an environmental features checklist that asks whether any of the following are present at the site: wetlands, waters of the United States, floodplains, and development infrastructure. Brief guidance is then provided on how to locate BMPs to avoid impacts to sensitive resources. If a BMP must be located within a sensitive environmental area, a brief summary of applicable permit requirements is provided.

In the last step, a designer assesses the physical and environmental features at the site to determine the optimal location for the selected BMP or group of BMPs (Table 4.5). The checklist below provides a condensed summary on current BMP restrictions as they relate to common site features that may be regulated under District or federal law. These restrictions fall into one of three general categories:

1. Locating a BMP within an area that is expressly *prohibited* by law.
2. Locating a BMP within an area that is *strongly discouraged*, and is only allowed on a case by case basis. District and/or federal permits shall be obtained, and the applicant will need to supply additional documentation to justify locating the BMP within the regulated area.
3. BMPs must be *set back* a fixed distance from the site feature.

This checklist is only intended as a general guide to location and permitting requirements as they relate to siting of stormwater BMPs. Consultation with the appropriate regulatory agency is the best strategy.

Table 4.6 Location and Permitting Considerations

Site Features and Relevant Agencies	Location and Permitting Guidance
Jurisdictional Wetland U.S. Army Corps of Engineers Section 404 Permit	▪ Delineate wetlands prior to locating BMPs. ▪ Use of natural wetlands for stormwater management is *strongly discouraged*. ▪ BMPs are also *restricted* in the 25 to 100 foot required wetland buffer. ▪ Buffers may be utilized as a non-structural filter strip (i.e., accept sheetflow). ▪ Must justify that no practical upland treatment alternatives exist. ▪ Stormwater must be treated prior to discharge into a wetland. ▪ Where practical, excess stormwater flows should be conveyed away from jurisdictional wetlands.
Stream Channel (Waters of the U.S.) U.S. Army Corps of Engineers Section 404 Permit	▪ Delineate stream channels prior to design. ▪ In-stream ponds (should be located near the origin of first order streams) are *strongly discouraged* and require review and permit. ▪ Must justify that no practical upland treatment alternatives exist. ▪ Temporary runoff storage (peak flow management) is preferred over permanent pools. ▪ Implement measures that reduce downstream warming.

Site Features and Relevant Agencies	Location and Permitting Guidance
100 Year Floodplain District of Columbia Homeland Security and Emergency Management Agency District Department of the Environment	▪ Grading and fill for BMP construction is *strongly discouraged* within the 100 year floodplain, as delineated by FEMA Flood Insurance Rate Maps (FIRM). ▪ Floodplain fill may be restricted with respect to impacts on surface elevation (DCMR 20, Chapter 31 Flood Hazard Rules>).
Utilities	▪ Locate existing utilities prior to design. ▪ Note the location of proposed utilities to serve new construction. ▪ Consult with each Utility on their recommended offsets ▪ Consider altering the location or sizing of the BMP to avoid or minimize the utility conflict. Consider an alternate BMP type to avoid conflict. ▪ Use design features to mitigate the impacts of conflicts that may arise by allowing the BMP and the utility to coexist. The BMP design may need to incorporate impervious areas, through geotextiles or compaction, to protect utility crossings. Other a key design feature may need to be moved or added or deleted. ▪ Coordinate with Utilities to allow them to replace or relocate their aging infrastructure during construction. ▪ If utility functionality, longevity and vehicular access to manholes can be assured accept the BMP design and location with the existing utility. Incorporate into the BMP design sufficient soil coverage over the utility or general clearances or other features such as an impermeable linear to assure all entities the conflict is limited to maintenance. ▪ When accepting utility conflict into BMP design, it is understood that the BMP will be temporarily impacted during utility work but the utility will replace the BMP or, alternatively, install a functionally comparable BMP according to the specifications in the current version of this Stormwater Management Guidebook. If the BMP is located in the public right-of-way the BMP restoration will also conform with the District of Columbia Department of Transportation Design and Engineering Manual with special attention to Chapter 33, Chapter 47, and the Design and Engineering Manual supplements for Low Impact Development and Green Infrastructure Standards and Specifications.
Public Right-of-Way District Department of Transportation	▪ BMP installation in PROW will require a DDOT Public Space Permit. ▪ Consult DDOT for guidance on placement and any setback requirement from local roads.

Site Features and Relevant Agencies	Location and Permitting Guidance
Structures District Department of Transportation District of Columbia Water and Sewer Authority Department of Consumer and Regulatory Affairs	▪ Consult review authority for BMP setbacks from structures. ▪ Recommended setbacks for each BMP group are provided in the performance criteria in Chapter 3.

4.7 References

Galli, John. 1992. Analysis of Urban BMP Performance and Longevity in Prince George's County, Maryland. Prepared for Prince George's County Department of Environmental Resources Watershed Protection Branch. Prepared by Metropolitan Washington Council of Governments, Department of Environmental Programs. Washington DC.

Chapter 5 Administration of Stormwater Management Rules

5.1 Stormwater Management Plans

For all major regulated projects, projects for the generation of Stormwater Retention Credit (SRC), and submissions for the Stormwater Fee Discount, the applicant is responsible for submitting a Stormwater Management Plan (SWMP) which meets the requirements defined within the Stormwater Management and Soil Erosion and Sediment Control Regulation (District of Columbia Municipal Regulations (DCMR) Title 21, Chapter 5), and the details outlined within this guidebook. Each SWMP submitted must be signed and sealed by a registered professional engineer, licensed in the District. All SWMP applications are reviewed by DDOE to determine compliance with the requirements of 21 DCMR, Chapter 5. A series of flow charts at the end of this chapter illustrate the SWMP review and approval process, within the overall context of the permitting process.

5.1.1 Submittal and Review Process of Stormwater Management Plans

A SWMP contains supporting computations, drawings, and sufficient information to evaluate the environmental characteristics of the affected areas, the potential impacts of the proposed development on water resources, the effectiveness and acceptability of best management practices (BMPs) and land covers for managing stormwater runoff, and maintenance and construction schedules. If the applicant proposes to use off-site retention the SWMP must indicate the number of gallons the applicant is required to retain off-site, termed Off-Site Retention Volume (Offv).

The applicant submits the SWMP, including two sets carrying the stamp of a registered professional engineer licensed in the District of Columbia with all supporting documentation, to the District of Columbia Regulatory and Consumer Affairs (DCRA). Projects may be submitted in person at the DCRA headquarters at 1100 4th Street SW, Second Floor, or through the DCRA online intake form available at http://cpms.dcra.dc.gov/OCPI/PermitMenu.aspx.

Some projects, for example, when the application is limited to Soil Erosion and Sediment Control Plans or Green Area Ratio, may be handled by DDOE staff located at the DCRA intake counter. All other projects will be forwarded for review to DDOE Headquarters at 1200 First Street NW, Fifth Floor. Other District agencies with review authority will also evaluate a project’s SWMP. For each project the applicant has the choice of submitting the SWMP electronically or in paper form. If the SWMP is submitted in paper form, then two plan sets of the project are required.

Upon receiving an application, DDOE will determine if the application is complete and acceptable for review, accept it for review with conditions, or reject the application.

Within 10 to 30 working days of the submission date of an accepted complete application DDOE will review the SWMP, and make a determination to approve, approve with conditions, or disapprove the SWMP. Relatively large and/or complicated projects tend to require longer review time than smaller and less complicated projects.

If it is determined that more information is needed or that a significant number of changes must be made before the SWMP can be approved, the applicant may withdraw the SWMP, make the necessary changes, and re-submit the SWMP. DDOE requires that all re-submissions contain a list of the changes made. A new 10–30 day review period begins on the date of the resubmission.

If SWMP approval is denied, the reasons for the denial will be communicated to the applicant in writing.

When a SWMP approval is granted, a final submission package is required, including

- One Mylar copy of the SWMP, certified by a registered professional engineer licensed in the District of Columbia.
- Seven paper copies of the SWMP, certified by a registered professional engineer licensed in the District of Columbia.
- All supporting documents specified within this SWMG or as requested during the review process by DDOE.

Note: The District of Columbia is in the process of creating a single electronic submission, review, and approval process for all DCRA building permit applicants. When DCRA migrates to the electronic submission process, this will become an alternate option for item 2 above in the final SWMP submission.

After the applicant submits a final package that meets the requirements for DDOE's approval, DDOE provides the applicant with one approved copy of the SWMP for the applicant to file at the Recorder of Deeds with the declaration of covenants and, if applicable, an easement.

Note: The applicant must submit the SWMP declaration of covenants to the Office of Attorney General (OAG) for legal sufficiency review. OAG approval is required before the SWMP can be filed with the Recorder of Deeds. Government Properties are exempt from this requirement but evidence of a maintenance partnership agreement or a maintenance memorandum of understanding is required prior to SWMP approval. There are six additional types of SWMP submissions that are not required to file a declaration of covenants, nor are they required to file easements. These are detailed in the exemptions Section 5.5 Exemptions.

The remaining approved paper copies of the approved SWMP are issued to the applicant after the submission of proof of filing the declaration of covenants, or evidence of a maintenance partnership agreement or a maintenance memorandum of understanding in the case of a government owned project, and each applicable easement with the Recorder of Deeds and proof of payment of applicable fee(s) for DDOE services.

Upon job completion, the applicant must certify on the approved SWMP that all activities including clearing, grading, site stabilization, the preservation or creation of pervious land cover, the construction of drainage conveyance systems, the construction of BMPs, and all other stormwater related components of the project were accomplished in strict accordance with the approved SWMP.

Within 21 days of the final inspection, the applicant must submit an as-built package, including one 1 Mylar copy of the as-built SWMP certified by a registered professional engineer licensed in the District of Columbia and one as-built form from Section 5.6 For a project consisting entirely of work in the public right-of-way, the submission of a Record Drawing certified by an officer of the project contracting company is acceptable if it details the as-built construction of the BMPs, related stormwater infrastructure and land covers.

The submission of a SWMP is supported by these documents:

1. Site Development Submittal Information Form
2. DC Water Storm Sewer Verification Form
3. DCRA Application for Construction Permit on Private Property
4. Environmental Intake Screening Form (EISF)
5. Environmental Questionnaire
6. DC Green Building Act Permit Application Intact Form
7. Contract Agreement
8. Lead Permit Screening Form
9. Zoning Data Summary Form
10. Reasonable Accommodations and Modifications for Persons with Disabilities Form

The forms 1 and 2 are found in Section 5.6. Supporting. Forms 3 through 10 are available at the DCRA intake counter, or they can be downloaded at http://dcra.dc.gov/DC/DCRA/Permits/Building+Permit+Application+Supplemental+Documents.

Note: In general, filing a Notice of Intent Form with US EPA is required if the project will disturb 1 or more acres of land, or part of a common plan of development or sale that will ultimately disturb 1 or more acres of land must file. Consult US EPA's web site for details, http://cfpub.epa.gov/npdes/stormwater/application_coverage.cfm

A Stormwater Management Plan (SWMP) includes the following:

Site Plan

The following information must be submitted on a standard drawing size of 24 inches by 36 inches. The site drawing will provide details of existing and proposed conditions:

a. A plan showing property boundaries and the complete address of the property.
b. Lot number, square number or parcel number designation (if applicable).
c. North arrow, scale, date.

d. Property lines (include longitude and latitude).
e. Location of easements (if applicable).
f. Existing and proposed structures, utilities, roads and other paved areas.
g. Existing and proposed topographic contours.
h. Soil information for design purposes.
i. Area(s) of soil disturbance.
j. Volume(s) of excavation.
k. Volume(s) of fill.
l. Volume(s) of backfill.
m. Drainage area(s) within the limits of disturbance (LOD) and contributing to LOD.
n. Delineation of existing and proposed land covers including natural cover, compacted cover and impervious surfaces. Consult Appendix N for details on land cover designations.
o. Location of existing stream(s), wetlands, or other natural features within the project area.
p. All plans and profiles must be drawn at a scale of 1 in. = 10 ft, 1 in. = 20 ft, 1 in. = 30 ft, 1 in. = 40 ft, 1 in. = 50 ft, or 1 in. = 80ft. Although, 1 in. = 10 ft, 1 in = 20 ft, and 1 in. = 30 ft, are the most commonly used scales. Vertical scale for profiles must be 1 in. = 2 ft, 1 in. = 4 ft, 1 in. = 5 ft, or 1 in. = 10ft.
q. Drafting media that yield first or second generation reproducible drawings with a minimum letter size of No. 4 (1/8 inch).
r. Location and size of existing utility lines including gas lines, sanitary lines, telephone lines or poles, and water mains.
s. A legend identifying all symbols used on the plan.
t. Applicable flood boundaries for sites lying wholly or partially within the 100-year floodplain.
u. Information regarding the mitigation of any off-site impacts anticipated as a result of the proposed development.
v. Stormwater Pollution Prevention Plan ($SWPPP_{CGP}$) (for projects disturbing over an acre) or Good House Keeping Stamp ($SWPPP_{min}$), details provided in Appendix Q (for sites under an acre).
w. Stormwater Hotspot Cover Sheet and Checklists, details provided in Appendix P.
x. Integrated Pest Management Plan for sites in the AWDZ governed by the by the Anacostia Waterfront Environmental Standards Amendment Act of 2012. Consult Appendix R for details on the IPM plan submission format.
y. Construction specifications.
z. Design and "As-Built" Certification.

i Certification by a registered professional engineer licensed in the District that the site design, land covers, and design of the BMPs conforms to engineering principles applicable to the treatment and disposal of stormwater pollutants.

ii Certification and submission of the As-Built Certification by Professional Engineer form (provided in at the end of this chapter) and one set of the "As-Built" plans within 21 days after completion of construction of the site, all BMPs, land covers, covers and stormwater conveyances. For a project consisting entirely of work in the public right-of-way, the submission of a Record Drawing certified by an officer of the project contracting company is acceptable if it details the as-built construction of the BMP and related stormwater infrastructure.

aa. Maintenance of best management practices

i A maintenance plan that identifies routine and long-term maintenance needs and a maintenance schedule must be submitted as part of the SWMP.

ii A declaration of covenants stating the owner's specific maintenance responsibilities identified in the maintenance plan and maintenance schedule. These must be exhibits recorded with the property deed, at the Recorder of Deeds. An example of a Declaration of Covenants is provided at the end of this chapter. Government owned properties are exempt from the declaration of covenants requirement but evidence of a maintenance partnership agreement or a maintenance memorandum of understanding is required that identifies who will implement the maintenance plan and maintenance schedule.

iii For applicants using BMP Group 2, Rainwater Harvesting, submission of third party testing of end use water quality may be required at equipment commissioning as determined by the Tiered Risk Assessment Management (TRAM) analysis. Additional regular water quality reports certifying compliance for the life of the BMP may also be required based on the TRAM analysis.

Stormwater Retention Volume Computations

a. Calculation(s) of required Stormwater Retention Volume (SWRv) for entire site within the limits of disturbance (LOD) and each individual drainage area contained within the LOD.
b. Calculation(s) for each proposed BMP demonstrating retention value towards SWRv in accordance with Chapter 3.
c. For BMP Group 2, Rainwater Harvesting, calculations demonstrating the annual water balance between collection, storage and demand.
d. For proprietary and non-proprietary BMPs outside the Stormwater Management Guidebook, complete documentation defined in Appendix S for BMP Group 12, Proprietary Practices, in Section 3.13 Proprietary Practices to identify/receive approval or denial to use these practice(s).

e. Deficit SWRv gallons requiring off-site mitigation.
f. Statement of participation in off-site mitigation program(s), in-lieu fee or retention credit trading to manage SWRv deficit.
g. For PROW projects (Type 1) complete MEP stormwater report as defined in Appendix B.
h. For PROW portions of projects (Type 2) complete MEP memo with supporting documentation as defined in Appendix B.

Pre/Post-Development Hydrologic Computations

The pre-/post-runoff analysis must include the following:

a. A summary of soil conditions and field data.
b. Pre-/post-project curve number computation.
c. Time of concentration calculation.
d. Travel time calculation.
e. Peak discharge computation for each drainage area within the project's limits of disturbance for the 24-hour storms of 2-year and 15-year frequencies. All hydrologic computations must be included on the plan.

Hydraulic Computations

Hydraulic computations for the final design of water quality and quantity control structures may be accomplished by hand or through the use of software using equations/formulae generally accepted in the water resources industry. The summary of collection or management systems will include the following:

a. Existing and proposed drainage area must be delineated on separate plans with the flow paths used for calculation of the times of concentration.
b. Hydraulic capacity and flow velocity for drainage conveyance, including ditch, swales, pipes, inlets, and gutter. Plan profiles for all open conveyance and pipelines, with energy and hydraulic gradients shown thereon.
c. The proposed development layout including the following:
   i Location and design of BMP(s) on site.
   ii Stormwater lines and inlets.
   iii Location and design of BMP(s) on site.
   iv A list of design assumptions (e.g., design basis, 15-year return period).
   v The boundary of the contributing drainage area to the BMP.
   vi Schedule of structures (a listing of the structures, details, or elevations including inverts

vii Manhole to manhole listing of pipe size, pipe type, slope, computed velocity, and computed flow rate (i.e., a storm drain pipe schedule).

5.1.2 Resubmission of Stormwater Management Plans

If a SWMP is accepted but changes occur in the design or construction, the applicant may be required to resubmit the SWMP for approval. Examples of changes during design and construction that may require re-submission include the following:

- A document in the original submission requires significant correction
- A document in the original submission is missing
- A document in the original submission has changed sufficiently to require replacement
- Relocation of an on-site storm sewer or conveyance
- Revision to methodology used for design of BMP(s)
- Modification to an approved BMP design, such as infiltration rates and contributing drainage areas
- Changes to the proposed land cover
- Changes to the selection, location or sizing of BMP(s)
- Changes to the size, invert, elevation and slopes of pipes and conveyances
- Installation of new drains and conveyance structures
- Installation or relocation of the sediment trap or basin
- Revision to the approved grading and drainage divides
- Removal of contaminated soil from the site
- Revision to the boundaries of the floodplain
- Revision to the property boundary
- New storm sewer outlet connection to the main storm or sanitary sewer
- Abandonment, removal or demolition of a BMP

If the applicant resubmits a SWMP after making changes, the re-submission must contain a list of the changes made. After DDOE's initial review and its review of the first resubmission, an applicant will pay the supplemental review fee for each subsequent review. Supplemental fees will not be assessed when a submission is for a project, or portion of a project, that is entirely in the existing public right-of-way and is following the Maximum Extent Practicable (MEP) process (see Appendix B).

5.2 Administration

5.2.1 Approval Requirements

A DDOE approved SWMP meeting the requirements of 21 DCMR, Chapter 5 is required before a building permit for any District project requiring stormwater management, as defined in Chapter 2 of this guidance manual is issued by the District of Columbia Department of Consumer and Regulatory Affairs (DCRA)

5.2.2 Fees

An applicant is responsible for paying fees that provide for the cost of review, administration, and management of the stormwater permitting process and inspection of all projects subject to the requirements of Chapter 5 of Title 21 of the District of Columbia Municipal Regulations Sections 516 through 539. These fees are posted on DDOE's website at http://ddoe.dc.gov/swregs and will be adjusted for inflation annually, using the Urban Consumer Price Index published by the United States Bureau of Labor Statistics.

Note: A supplemental plan review fee is required for each DDOE review after first resubmission of a plan. Phased review requirements that follow the Maximum Extent Practicable (MEP) process (see Appendix B) for a project, or portion of a project, entirely in the existing public right-of-way are not required to pay a supplemental review fee.

Note: There is no fee charged for the plan review of a SWMP submitted solely to obtain the Stormwater Fee Discount.

5.3 Inspection Requirements

5.3.1 Inspection Schedule and Reports

Prior to the approval of a SWMP, the applicant will submit a proposed construction and inspection control schedule. DDOE will review the schedule to determine if changes are required. The construction schedule should reflect the construction sequences defined in each BMP section of Chapter 3 of this guidebook. The construction and inspection schedule must be included in the SWMP. DDOE will conduct inspections at the construction stages specified in the provisions, and file reports of inspections during construction of BMPs and site stormwater conveyance systems to ensure compliance with the approved plans.

Note: No stormwater management work may proceed past the stage of construction that DDOE has identified as requiring an inspection unless,

- DDOE has issued an "approved" or "passed" report;
- DDOE has approved a plan modification that eliminates the inspection requirement; or
- DDOE has eliminated or modified the inspection requirement in writing.

DDOE may require that the professional engineer responsible for sealing the approved SWMP, the professional engineer responsible for certifying the "As-Built" SWMP, or, for a project entirely in the PROW, the officer of the contracting company responsible for certifying the Record Drawing be present during inspections.

A written notice from DDOE of an inspection finding work not in compliance with the approved SWMP requires the applicant to take prompt corrective action. The written notice provide details on the nature of corrections required and the time frame within which corrections must be made.

5.3.2 Inspection Requirements Before and During Construction

DDOE's construction inspection checklists for each BMP are provided in Appendix K.

Preconstruction Meetings. These meetings are required prior to the commencement of any land-disturbing activities and prior to the construction of any on-site or off-site BMPs.

The applicant is required to contact DDOE to schedule preconstruction meetings 3 days prior to beginning any construction activity subject to the requirements of 21 DCMR, Chapter 5.

Inspections During Construction. The applicant is required to contact DDOE to schedule inspection 3 days prior to any stage of BMP construction, or other construction activity, requiring an inspection. For large, complicated projects the applicant and DDOE may agree during the preconstruction meeting to an alternative approach such as a weekly notification schedule. Any such agreement must be made in writing and signed by all parties. DDOE will revert to the 3 day notification procedure if the agreement is not followed.

DDOE may require the professional engineer responsible for sealing the approved SWMP, or the professional engineer responsible for certifying the "As-Built" SWMP, or for a project entirely in the PROW, the officer of the contracting company responsible for certifying the Record Drawing be present during inspections.

Final Inspection. The applicant is required to contact DDOE to schedule a final inspection 1 week prior to the completion of a BMP construction to schedule a final inspection of the BMP.

A final inspection will be conducted by DDOE upon completion of the BMP to determine if the completed work is constructed in accordance with approved plans.

Inspection Requirements by BMP Type. Chapter 3 of this Guidance Manual provides details about the construction sequences for each BMP. After holding a preconstruction meeting, regular inspections will be made at the following specified stages of construction:

- **Infiltration Systems and Bioretention Areas.** shall be inspected at the following stages so as to ensure proper placement and allow for infiltration into the subgrade:
  - (a) During on-site/off-site percolation/infiltration test
  - (b) Upon completion of stripping, stockpiling, construction of temporary sediment control and drainage facilities
  - (c) Upon completion of excavation to subgrade

(d) Throughout the placement of perforated PVC/HDPE pipes (for underdrains and observation wells) including bypass pipes (where applicable), geotextile materials, gravel, or crushed stone course and backfill

(e) Upon completion of final grading and establishment of permanent stabilization

- **Flow Attenuation Devices**, such as open vegetated swales upon completion of construction
- **Retention and Detention Structures**, at the following stages:

(a) Upon completion of excavation to sub-foundation and where required, installation of structural supports or reinforcement for structures, including but not limited to the following:

- Core trenches for structural embankments
- Inlet-outlet structures and anti-seep structures
- Watertight connectors on pipes
- Trenches for enclosed stormwater drainage facilities

(b) During testing of the structure watertightness

(c) During placement of structural fill, concrete and installation of piping and catch basins

(d) During backfill of foundations and trenches

(e) During embankment construction

(f) Upon completion of final grading and establishment of permanent stabilization

- **Stormwater Filtering Systems**, at the following stages:

(a) Upon completion of excavation to sub-foundation and installation of structural supports or reinforcement for the structure

(b) During testing of the structure watertightness

(c) During placement of concrete and installation of piping and catch basins;

(d) During backfill around the structure

(e) During prefabrication of structure at manufacturing plant

(f) During pouring of floors, walls and top slab;

(g) During installation of manholes/trap doors, steps, orifices/weirs, bypass pipes, and sump pit (when applicable)

(h) During placement of filter bed

(i) Upon completion of final grading and establishment of permanent stabilization

- **Green Roof Systems**, at the following stages:

(a) During placement of the waterproofing layer, to ensure that it is properly installed and watertight

(b) During placement of the drainage layer and drainage system

(c) During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth (certification for vendor or source must be provided)

(d) Upon installation of plants, to ensure they conform to the planting plan (certification from vendor or source must be provided)

(e) At the end of the first or second growing season, to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved

5.3.3 Final Construction Inspection Reports

DDOE will conduct a final inspection to determine if the completed work is constructed in accordance with approved plans and the intent of 21 DCMR, Chapter 5. A registered professional engineer licensed in the District is required to certify “As-Built" plans and state that the BMP has been constructed in accordance with the approved plans and specifications (the As-Built Certification by Professional Engineer form is provided in Appendix A. The "As-Built" certification must be on the original SWMP. Upon completion, these plans will be submitted to the DDOE for processing. The estimated time for processing will be two weeks (ten working days), after which the plans will be returned to the engineer. DDOE will provide the applicant with written notification of the final inspection results. DDOE will maintain a permanent file of inspection reports.

5.3.4 Inspection for Preventive Maintenance

Preventive maintenance will be ensured through inspection of all BMPs by DDOE. The inspection will occur at least once every three years. Maintenance inspection forms are provided in Appendix L.

Preventive maintenance inspection reports will be maintained by DDOE on all BMPs. The reports will evaluate BMP functionality based on the detailed BMP requirements of Chapter 3 and inspection forms found in Appendix L.

If, after an inspection by DDOE, the condition of a BMP presents an immediate danger to the public safety or health because of an unsafe condition or improper maintenance, the DDOE will take such action as may be necessary to protect the public and make the BMP safe. Any costs incurred by DDOE will be assessed against the owner(s).

5.4 Maintenance

5.4.1 Maintenance Responsibility

A site with an approved SWMP must maintain the BMPs and land covers according to the maintenance schedule in the SWMP. Land covers must be maintained in type and extent as approved. Approved BMPs must be kept in good condition all the engineered and natural elements of each practice, as well as conveyance features (e.g., grade surfaces, walls, drains, structures, vegetation, soil erosion and sediment control measures, and other protective devices). All repairs or restorations must be in accordance with the approved SWMP.

A declaration of covenants including an exhibit stating the owner's specific maintenance responsibilities must be recorded with the property deed, at the Record of Deeds. A maintenance schedule for any BMP will be developed for the life of the project and shall state the maintenance to be completed, the time for completion, and who will perform the maintenance including provisions for normal and abnormal maintenance. The maintenance schedule will be printed on the SWMP and will appear as an exhibit in the declaration of covenants.

5.4.2 Maintenance Agreement

DDOE will not issue final approval of a complete set of the SWMP for private parcels until the applicant has executed a declaration of covenants binding current and subsequent owners of the land served by the BMP(s) and land covers to an inspection and maintenance agreement. Such agreement shall provide for access to the site and the BMP(s) at reasonable times, and for regular inspection by DDOE, and for regular or special assessments of property owners, as needed, to ensure that the BMP(s) is maintained in proper working condition and the land covers are retained as approved in the SWMP. An example of the declaration of covenants for a site with BMPs and designated land covers is provided at the end of this chapter.

The agreement must be recorded as a declaration of covenants with the Recorder of Deeds of the District by the applicant. The agreement must also provide that, if after written notice by DDOE to correct a violation requiring maintenance work, satisfactory corrections are not made by the owner(s) of the land served by the BMP within a reasonable period of time, not to exceed 45-60 days unless extended for good cause shown, DDOE may perform all necessary work to place the BMP in proper working condition. The owner(s) of property served by the BMP will be assessed the cost of the work and any penalties and there will be a lien on any property served by the BMP, which may be placed on the tax bill and collected as ordinary taxes by the District.

5.5 Exemptions

If a major substantial improvement activity demonstrates that it is not part of a common plan of development with a major land-disturbing activity, then it is exempt from the 2-year and 15-year storm-control requirements.

If DDOE determines that a land-disturbing activity is conducted solely to install a BMP or land cover for any of the following six reasons:

1. To generate a Stormwater Retention Credit,
2. To earn a stormwater fee discount under the provisions of this chapter,
3. To provide for off-site retention through in-lieu fee payments,
4. To comply with a Watershed Implementation Plan established under a Total Maximum Daily Load for the Chesapeake Bay, or
5. To reduce Combined Sewer Overflows (CSOs) in compliance with a court-approved consent decree, including court-approved modifications, for reducing CSOs in the District of Columbia, or in compliance with a National Pollutant Discharge Elimination System permit,

then these SWMPs are exempt from stormwater performance requirements for major land disturbing activities and stormwater performance requirements for major substantial improvements activities, as well as requirements for covenants and easements. The stormwater obligations for these sites generating SRCs are detailed in Chapter 7 of this guidance manual.

Note: While the declaration of covenants and easements are not required with these projects, an executed maintenance contract or a signed promise to follow the Department-approved maintenance plan for the period of time for which the certification of SRCs is requested is required for SWMP approval. If the site fails to maintain these retention practices DDOE has recourse that is spelled out in Chapter 5 and Chapter 7 of this guidance manual.

Land-disturbing activities that consist solely of cutting a trench for utility work and related replacement of sidewalks and ramps are exempt from stormwater management requirements if the activity does not involve the reconstruction of a roadway from curb to curb or curb to centerline of roadway.

Land-disturbing activities conducted solely to respond to an emergency need to protect life, limb, or property or to conduct emergency repairs are exempt from most stormwater management requirements. These activities are not required to submit a SWMP, but they are subject to inspections to ensure the proper use of soil erosion and sediment control measures.

5.6 Supporting Forms

- Site Development Submittal Information Form
- DC Water DDOE WPD Storm Sewer Verification Form
- As-Built Certification Stamp
- Declaration of Covenants Template

GOVERNMENT OF THE DISTRICT OF COLUMBIA
District Department of the Environment

Site Development Submittal Form

Property Location: ____________________

Development Review Type: ____________________

Lot # ____________ Square # ____________ Parcel # ____________

Type/Description of Work: □ Single Family, □ Duplex, □ Townhouses, □ Condominium, □ Office Building
□ Apartment Building □ Industrial Building □ Parking Lot □ Foreign Govt. Office/Residence
□ Federal land/property □ District land/property □ District roadway □ Other (specify) ____________

Property Owner:
Name: ____________ Phone#: ____________ Fax#: ____________

Applicant:
Name (First): ____________ (Last): ____________ Phone# ____________

Fax#: ____________ E-Mail: ____________

Street Address: ____________ City: ____________ State: ______ Zip: ______

□ Designer □ Engineer □ Architect: (Check one or more)
Firm: ____________ Phone# ____________ Fax# ____________

Street Address: ____________ City: ____________ State: ______ Zip: ______

Contact Person: ____________ E-Mail ____________

Check List:
□ Initial review submission, two sets of civil drawings
□ Copy of Department of Consumer Regulatory Affairs (DCRA) permit application
□ Signed Department of Consumer Regulatory Affairs (DCRA) Environmental Intake Form

My signature attests that the attached application package is complete and accurate to the best of my knowledge. I understand that property review of this plan depends upon the accuracy of the information, and that inaccurate information submitted by me, my firm, or agent may delay this project.

Signature: ____________ ***Date:*** ____________

DISTRICT DEPARTMENT OF THE ENVIRONMENT green forward

1200 First St. NE, 5th Floor, Washington, DC 20002 | tel: 202.535.2600 | web:ddoe.dc.gov

ONE CITY

Figure 5.1 Site Development Submittal Information form.

GOVERNMENT OF THE DISTRICT OF COLUMBIA
DISTRICT DEPARTMENT OF THE ENVIRONMENT

Application for Discharge from New Stormwater Management BMP

1. ***Proposed Discharge from Stormwater Best Management Practice (BMP) By Applicant:***
   A. BMP Type:____________________________________
   B. Project Location:____________________________________
   __________________________Square: _________________Lot:____________
   C. Post-development Peak Flows:
   ☐ 15-Year__________cfs; ☐ 2-Year___________cfs.
   D. Receiving System Type, Location, Slope, and Depth:
   ☐ Combined Sewer ☐ Separate Sewer
   ☐ Depth: 5ft ☐ Yes ☐ No ☐ Specify: _________________
   ☐ Slope: 2% ☐ Yes ☐ No ☐ Specify: _________________
   ☐ Groundwater Depth: ______________ft.
   ☐ Surface Water Ways: ______________________________________
   Discharge Location Or Name Of The Surface Waterways: _________________
   ____
   E. The proposed Invert Connection Elevation: ________________________ ft.
2. ***Hydraulic Sewer System Verification By DCWater*:**
   A. Combined Sewer Area ☐ Yes ☐ No. **B.** Separate Sewer Area: ☐ Yes ☐ No
   C. The Sewer System Is Within __________________ ft.
   D. Maximum Depth 5 ft. ☐ Yes ☐ No **E.** Slope ≥2% ☐ Yes ☐ No ☐ _______
3. ***Surface Water & Groundwater Ways Verification By Watershed Protection Division:***
   A. Surface Water Ways:
   ☐ Max. Flow Allowed: ________cfs ☐ Max. Velocity Allowed: ________ft/sec
   B. Groundwater:
   ☐ Minimum Infiltration Allowed: ________________ft/hr

Requested By:__________________________________ ☐ Agent ☐ Owner
Address : ____
Tel: ( ) ____________ Fax: ( ) ______________ Date Requested: ______________

DC Water Verification: By: (Name)___________________________, Title _________________
Tel: ( ) ____________ Fax: ( ) ______________ Date Verified: ________________

DDOE WPD Verification By: (Name)___________________________, Title _________________
Tel: ( ) ____________ Fax: ( ) ______________ Date Verified: ________________
Notes:____

Figure 5.2 DC Water DDOE WPD storm sewer verification form.

AS-BUILT CERTIFICATION BY PROFESSIONAL ENGINEER

Within 21 days after completion of construction of the Stormwater discharge facility, please send this page to the Watershed Protection Division of the District Department of the Environment.

1. ***Stormwater discharge facility information:***

Source Name:____

Source Location: Street:____________________________________

City:____________________________________

DCRA Permit No.:__________________________

Date Issued:______________________

2. ***As Built Certification***

I hereby certify that Stormwater discharge facility has been built substantially in accordance with the approved plans and specifications, and that any substantial deviations (noted below) will not prevent the system from functioning in compliance with the requirements of Section 526 through 535 of DCMR-21, Chapter 5 when properly maintained and operated. These determinations have been based upon on-site observation of construction, scheduled and conducted by me or by a project representative under my direct supervision. I have enclosed one set of as-built engineering drawings.

____________________________________ ____________________________________

Signature of Engineer Name (Please Type) D.C. Reg. No.

Affix Seal:

____
Company Name

____
Company Address

____

Date: _________________ Phone No.________________

Substantial deviations from the approved plans and specifications (attach additional sheets if required).

____

____

____

____

Figure 5.3 As-built certification stamp.

THE GOVERNMENT OF THE DISTRICT OF COLUMBIA

District Department of the Environment
NATURAL RESOURCES ADMINISTRATION
WATERSHED PROTECTION DIVISION

DECLARATION OF COVENANTS
For a Storm Water Management Facility

THIS DECLARATION OF COVENANTS (the "**Declaration**") is made as of this _____ day of _________, 20__, by and between LIST NAME OF OWNER, a LIST TYPE OF CORPORATION/PROPERTY OWNER, and its successors and assigns ("Owner"), for the benefit of the DISTRICT OF COLUMBIA, a municipal corporation (the "**District**").

RECITALS

A. The Owner is the owner in fee simple of certain real property and improvements (collectively, the "**Property**") located in the District of Columbia and more particularly described in **Exhibit A** attached hereto and made a part hereof. No other person or entity has an ownership interest in the Property.

B. In order to accommodate and regulate changes in storm water flow conditions resulting from certain improvements Owner will make to the property, Owner shall construct and agrees to maintain, at its sole expense, a storm water management facility and sustainable design features (collectively, the "**Facility**") identified as ____________________________________, pursuant to the plans approved by the District (and as the same may be amended after District's approval) attached hereto as **Exhibit B** as the Site Plan.

C. Title 21 of the District of Columbia Municipal Regulations ("**DCMR**") Sections 534.2, 534.3, and 534.4 require that an owner maintain any storm water management facility on its property in good condition, develop and submit for approval a maintenance schedule for any such storm water management facility, and execute and record with the Recorder of Deeds of the District a covenant setting forth the owner's aforementioned maintenance responsibilities with specificity.

NOW, THEREFORE, for and in consideration of the issuance of construction permits and approval of Owner's plans by the District, and other good and valuable consideration the sufficiency of which is hereby acknowledged, for the benefit of and limitation upon Owner and all future owners of the Property, and for the benefit of the District, Owner for itself, its successors and assigns, does hereby acknowledge, represent, covenant, agree, and warrant to the District as follows:

1. The foregoing Recitals and attached Exhibits are all hereby incorporated in and made a part of this Declaration to the same extent as if herein set forth in full, provided however, that said Recitals shall not be deemed to modify the express provisions hereinafter set forth.

Figure 5.4 Declaration of Covenants template.

2. Owner shall construct and perpetually operate and maintain the Facility in such manner as to comply with the provisions of Title 21, Chapter 5 of DCMR at its sole expense and in strict accordance with the development and maintenance plan approved by the District. Specifically, Owner shall be responsible for the maintenance of the Facility in accordance with the maintenance standards attached hereto as **Exhibit C**.

3. Owner shall, at its sole expense, make such changes or modifications to the Facility as may, in the District's discretion, be determined necessary to insure that the Facility is maintained in good condition and continues to operate as designed and approved.

4. The District and its agents, employees and contractors shall have the right to enter the Property for the purpose of inspecting the Facility in accordance with established inspection procedures and Section 16 of the Water Pollution Control Act of 1984 (D.C. Law 5-188; 32 DCR 919; D.C. Official Code §8-103.01, *et seq.* (2007 Supp.), and as amended, (the "Act"), at reasonable times and in a reasonable manner, in order to insure that the Facility is being properly maintained and is continuing to perform in the manner approved by the District.

5. Should Owner fail to perform its maintenance responsibilities as set forth herein and as contained in any and all plans submitted to and approved by the District, or fail to operate and, where necessary, restore the Facility in accordance with the approved design standards, as the same may be amended from time to time, and in accordance with all applicable laws and regulations, the District shall be entitled to pursue any and all enforcement actions available to it pursuant to the Act and Title 21, Chapter 22 of the DCMR, as the same may be amended or revised from time to time. Without limiting the generality of the foregoing, in the event that a discharge or threat of discharge from the Facility poses an imminent and substantial danger to the public health or welfare, the District may take immediate action against Owner pursuant to either Section 21-2207 or Section 21-2211.2 of the DCMR.

6. If Owner's failure or refusal to maintain the Facility in accordance with the covenants and warranties contained in this Declaration ultimately results in duly authorized corrective action by the District, Owner shall bear all costs incurred by the District for such corrective measures, such costs may be assessed against the Property, and Owner may be fined in accordance with the Act and Title 21, Chapter 5 of the DCMR.

7. The provisions of this Declaration shall be deemed warranties by the Owner and covenants running with the land and shall bind and inure to the benefit of Owner and the District, their respective heirs, successors and/or assigns. When Owner ceases to own an interest in the Property, the rights, warranties, and obligations under this Declaration shall become the rights, warranties, and obligations of the successor-in-ownership and interest as to the Property.

8. Owner shall, at its cost and expense, properly record this Declaration with the Recorder of Deeds and furnish the District's Department of the Environment and Office of the Attorney General with a copy of this Declaration, certified by the Recorder of Deeds as a true copy of the recorded instrument.

9. Owner shall indemnify, save harmless, and defend the District, and all its officers, agents, and employees from and against all claims or liabilities that may arise out of or in

2

Figure 5.4 (continued)

connection with, either directly or indirectly, any of Owner's actions or omissions with regard to the construction, operation, maintenance and/or restoration of the Facility.

10. Owner shall insure that all prior liens recorded against the Property are subordinate to this Declaration. Failure to subordinate any such liens may give rise to termination of any building permits and/or invalidation of any certificate of occupancy relating to the Property.

11. Owner shall, at its sole expense, comply with all provisions of this Declaration regardless of any conflicting requirements in any other covenant, easement, or other legal document recorded or unrecorded against the Property. Neither the entering into of this Declaration nor performance hereunder will constitute or result in a violation or breach by Owner of any other agreement or order which is binding on the Owner.

12. To the extent the Owner is an entity, the Owner warrants that it is (i) duly organized, validly existing and in good standing under the laws of its state of jurisdiction and is qualified to do business and is in good standing under the laws of the District of Columbia, (ii) is authorized to perform under this Declaration and (iii) has all necessary power to execute and deliver this Declaration.

13. The form of this Declaration has been approved by the District of Columbia Office of the Attorney General for legal sufficiency pursuant to Title 12A, Section 106.6 of the D.C.M.R. This Declaration, and the provisions contained herein, may not be modified, amended, or terminated without the prior written consent of the District and legal sufficiency approval by the District of Columbia Office of the Attorney General, such agreement to be evidenced by a document duly executed and delivered in recordable form and recorded with the Recorder of Deeds at no expense to the District.

14. The District has the right to specifically enforce this Declaration.

15. This Declaration shall be governed by, construed and enforced in accordance with, the laws of the District of Columbia.

16. This Declaration has been duly executed and delivered by the Owner, and constitutes the legal, valid, and binding obligations of the Owner, enforceable against the Owner and its successors and assigns, in accordance with its terms.

17. If any of the covenants, warranties, conditions or terms of this Declaration shall be found void or unenforceable for whatever reason by any court of law or of equity, then every other covenant, condition or term herein set forth shall remain valid and binding.

[SIGNATURES FOLLOW]

3

Figure 5.4 (continued)

IN WITNESS WHEREOF, Owner has, as of the day and year first above written, caused this Declaration of Covenants to be signed by LIST NAME OF OWNER, a LIST TYPE OF CORPORATION/PROPERTY OWNER.

By: _______________________________

Signature
LIST NAME
LIST TYPE OF COMPANTY/PROPERTY OWNER

NOTARIZATION

______LIST STATE____________)
) ss:
______LIST COUNTY__________)

I, LIST NAME OF NOTARY, a Notary Public in and for the jurisdiction aforesaid, do hereby certify that LIST NAME OF PERSON SIGNING ON BEHALF OF OWNER, party to the foregoing Declaration of Covenants, personally appeared before me and, being personally well known to me, who has been appointed its attorney-in-fact and has acknowledged said Declaration of Covenants to be the act and deed of LIST NAME OF OWNER/LIST NAME OF COMPANY IN CAPACITY AS OWNER/PROPERTY OWNER, and that s/he delivered the same as such.

GIVEN under my hand and seal this ____ day of ________, 2009.

____
Notary Public

My commission expires:

[NOTARIAL SEAL]

4

Figure 5.4 (continued)

APPROVED AS TO TECHNICAL SUFFICIENCY:

District of Columbia
District Department of the Environment
Natural Resources Administration
Watershed Protection Division

By: ___________________________________
Name: _________________________________
Title: _________________________________
Date: ______________________

APPROVED AS TO LEGAL SUFFICIENCY:

District of Columbia Office of the Attorney General
Real Estate Section

By: ___________________________________
Assistant Attorney General
Date: ___________________

5

Figure 5.4 (continued)

EXHIBIT A
[LEGAL DECRIPTION]

EXHIBIT B
[SITE PLAN]

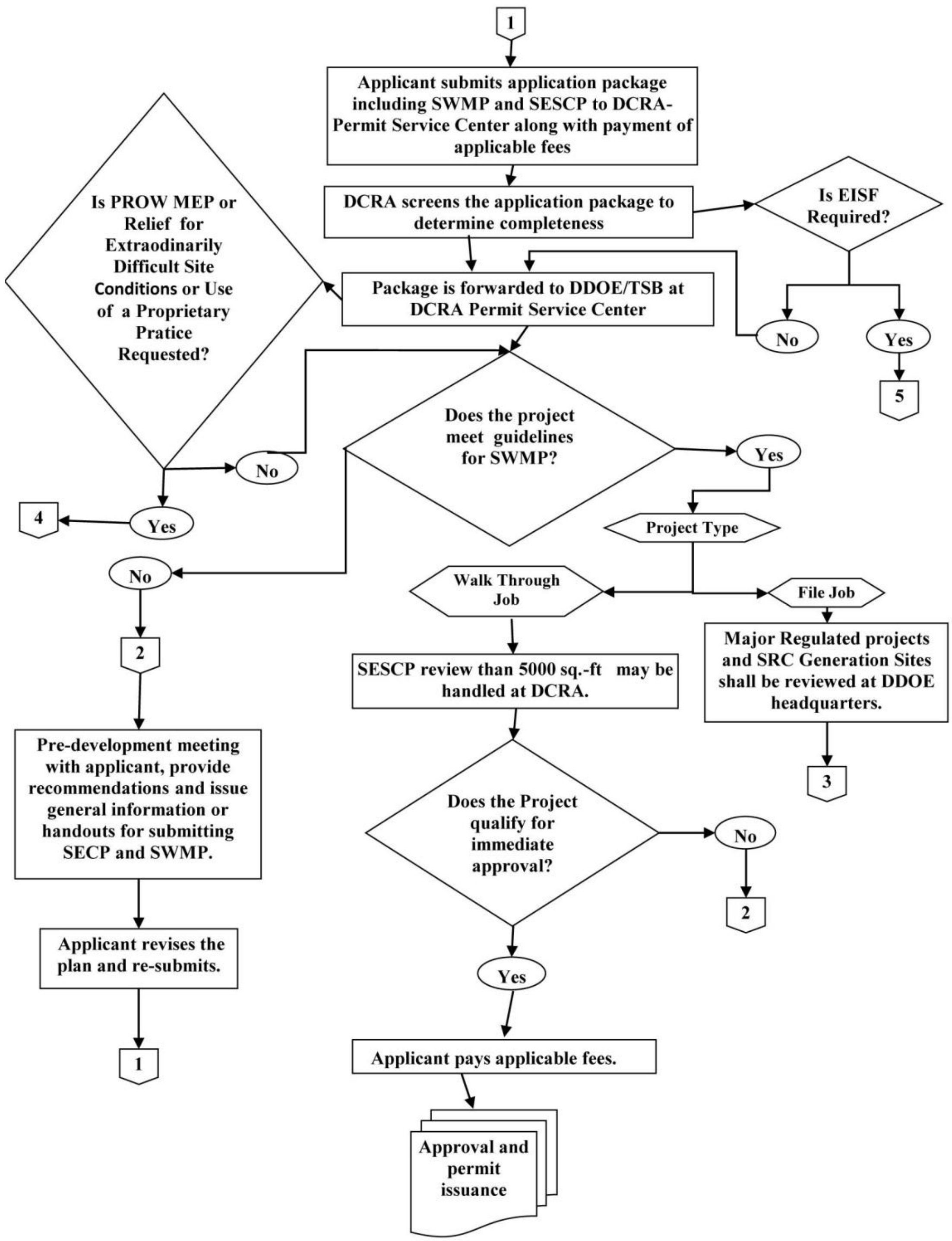
EXHIBIT C
[MAINTENANCE SCHEDULE]]

6

Figure 5.4 (continued)

5.7 Flow Diagram of Plan Review Process

Flow charts, in Figures 5.1 through 5.4 illustrate the five steps in DDOE's review of a Stormwater Management Plan (SWMP) and Soil Erosion and Sediment Control Plan in the context of the overall permitting process, which includes the Environmental Impact Statement Form (EISF) process.

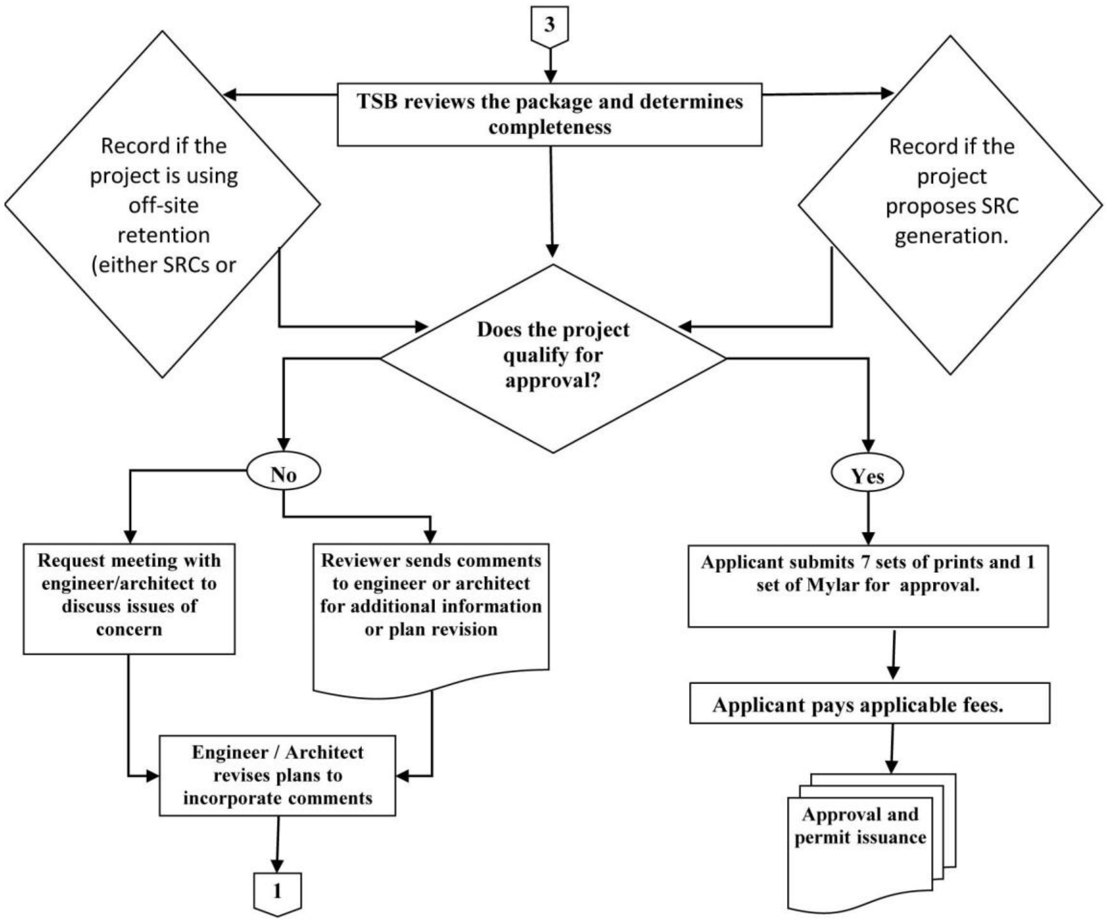


Note:

SESCP : Soil Erosion and Sediment Control Plan
SWMP : Storm Water Management Plan
ERC : Environmental Review Coordinator
PROW: Public Right of Way
SRC: Stormwater Retention Credit
DCRA: Department of Consumer and Regulatory Affairs
EISF: Environmental Impact Screening Form
TSB: Technical Services Branch
MEP: Maximum Exent Practicable

Revision Date: 08/15/2012

Figure 5.5 Stormwater Management and Soil Erosion and Sediment Control Plan Review, Steps 1 and 2.

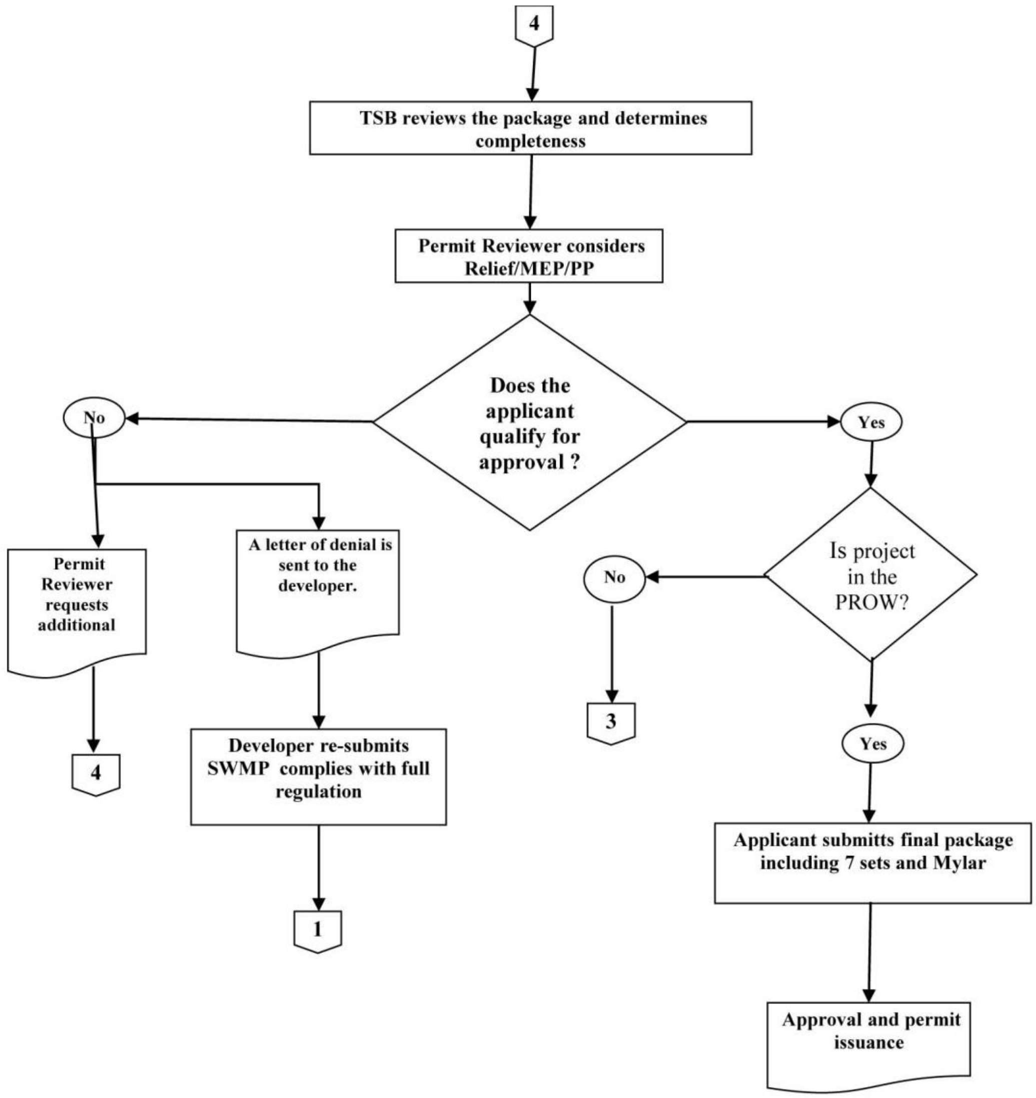


Note:

SESCP : Soil Erosion and Sediment Control Plan
SWMP : Storm Water Management Plan
ERC : Environmental Review Coordinator
PROW: Public Right of Way
SRC: Stormwater Retention Credit
DCRA: Department of Consumer and Regulatory Affairs
EISF: Environmental Impact Screening Form
TSB: Technical Services Branch
MEP: Maximum Exent Practicable

Revision Date: 08/15/2012

Figure 5.6 Stormwater Management and Soil Erosion and Sediment Control Plan Review, Step 3.



Note:

SESCP : Soil Erosion and Sediment Control Plan
SWMP : Storm Water Management Plan
ERC : Environmental Review Coordinator
PROW: Public Right of Way
Relief: Relief for Extraordinarily Difficult Site Conditions
PP: Proprietary Practice
SRC: Stormwater Retention Credit
DCRA: Department of Consumer and Regulatory Affairs
EISF: Environmental Impact Screening Form
TSB: Technical Services Branch
MEP: Maximum Exent Practicable

Revision Date: 08/15/2012

Figure 5.7 Stormwater Management and Soil Erosion and Sediment Control Plan Review, Step 4.

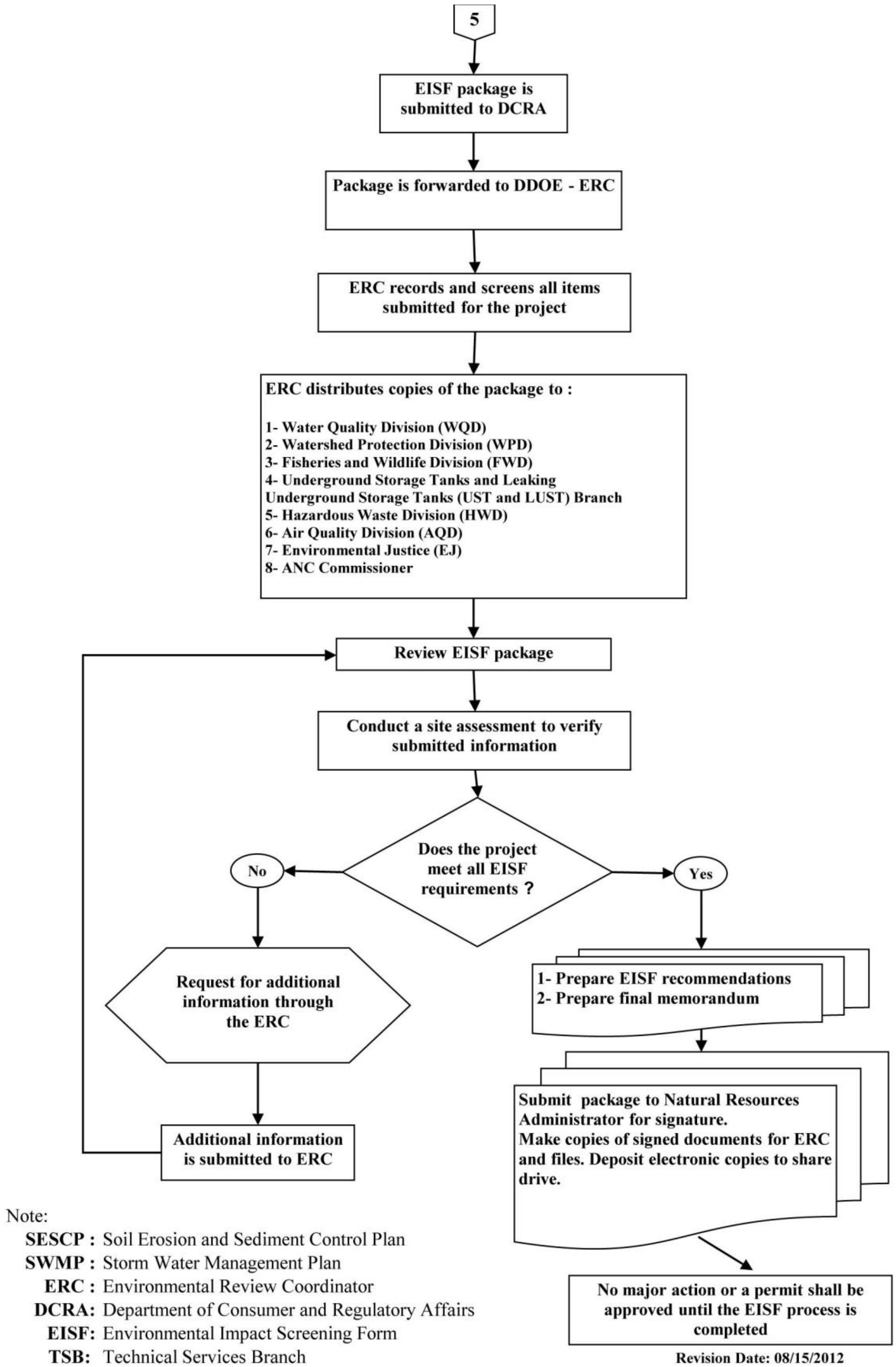


Figure 5.8 Stormwater Management and Soil Erosion and Sediment Control Plan Review, Step 5.

Chapter 6 Use of Off-Site Retention by Regulated Sites

6.1 Off-Site Retention Overview

A regulated site must retain a minimum volume on site that is equal to 50 percent of the SWRv. Above that minimum on-site volume, the regulated site may use off-site retention without having to first demonstrate that it would be infeasible to retain that volume on site. However, in order to retain less than the minimum on-site volume, the site must demonstrate that on-site retention of that volume is technically infeasible or environmentally harmful.

The portion of a SWRv that a regulated site does not retain on site is termed the Off-Site Retention Volume or Offv, and a regulated site's options for achieving its Offv are the following:

a. Use Stormwater Retention Credits (SRCs), each of which corresponds to one gallon of retention for one year; or
b. Pay DDOE's in-lieu fee (ILF), the cost of which corresponds to one gallon of retention for one year; or
c. A combination of (a) and (b).

The owner of a regulated site may use SRCs that the owner has earned elsewhere in the District or SRCs purchased on the private market. DDOE will provide the regulated site with contact information for SRC owners who wish to sell their SRCs. SRC buyers and sellers negotiate the terms of a transaction between themselves, but the transaction is not complete until DDOE has approved it. DDOE's approval is required so that DDOE can effectively track ownership and use, including preventing fraudulent use of SRCs, and also publicly share the price at which SRCs sell.

Regulated sites are responsible for their Offv on an ongoing basis, just as they must maintain any on-site stormwater best management practices (BMPs) on an ongoing basis. In other words, they must continue to use SRCs or pay in-lieu fee for the life of the development, similar to paying a lease or utility fee. However, if in the future a regulated site retrofits and achieves its Offv on site, then it no longer must achieve that volume off site.

A regulated site may meet its Offv for multiple years by paying up front for sufficient in-lieu fee to satisfy its Offv for that time period. Likewise, the regulated site may purchase and commit to use sufficient SRCs to satisfy its Offv for multiple years. SRCs may be banked indefinitely. The one year lifespan of an SRC or in-lieu fee payment begins once it is used to satisfy an Offv.

Once SRCs have been used or sold, they remain valid, even if the owner of the retention practices for which SRCs were certified fails to maintain them. Note, however, that there are consequences for original SRC owners who fail to maintain retention practices for which SRCs have been certified, as discussed in Chapter 7 and Appendix D.

Each SRC will have a unique serial number, and DDOE will track how a regulated site is satisfying its Offv. DDOE will automatically assess an in-lieu fee, with penalties for late payment, for any site that does not stay current with its Offv obligation. DDOE may also take other action, including enforcement action, against a regulated site for failure to comply with an Offv.

The Stormwater Management Plan (SWMP) for a regulated site opting to use off-site retention must state its Offv. This Offv, along with related requirements for sites in the Anacostia Waterfront Development Zone, will be recorded in the declaration of covenants filed for the property. Whether using in-lieu fee or SRC, they must be in use as of the successful completion of DDOE's final inspection at the end of the construction process.

6.2 Off-Site Retention via Stormwater Retention Credits

One SRC satisfies one gallon of Off-Site Retention Volume (Offv) for one year. The use of an SRC is not restricted by watershed. However, for every gallon of Offv that an Anacostia Waterfront Development Zone (AWDZ) site elects to meet with SRCs from outside the Anacostia River watershed, it must use 1.25 SRCs.

A regulated site with an Offv may elect at a future date to install additional stormwater best management practices (BMPs) on site in a sufficient volume to eliminate or reduce the Offv.

To use SRCs to meet an Offv, a regulated site owner must submit an application to use SRCs to meet its Offv (see Appendix C). The application must identify SRCs that are owned by the site owner and may cover multiple years of Offv. The application must be submitted 30 days in advance of the planned date of use. SRCs (and/or in-lieu fee) must be in use as of the successful completion of DDOE's final inspection at the end of the construction process and thereafter on an ongoing basis.

After verifying the ownership of the SRCs and other information in the application to use SRCs, DDOE will approve the use of the SRCs. DDOE will not sign off on a regulated site's final inspection at the end of the construction process until it has approved the application and verified that any Offv is achieved. The one-year lifespan of the SRCs begins as of the date that it is used to meet the Offv.

At least 30 days before SRCs used to satisfy an Offv are set to expire, the regulated site owner must submit an application identifying additional SRCs that will be used to satisfy the Offv or pay in-lieu fee.

If DDOE does not receive an application to use SRCs or an in-lieu fee payment and a lapse in compliance with an Offv occurs, DDOE shall charge an in-lieu fee, with a 10 percent late fee, to the regulated site owner and provide notice to the site owner accordingly. For a site owner who does not comply within 30 days of DDOE's notice of a lapse in satisfaction of an Offv obligation and who owns an SRC that has not been used to satisfy the Offv for another site, DDOE may apply that SRC to the Offv that is out of compliance. DDOE may also take enforcement action against a regulated site that fails to comply with an Offv.

Summary of Key Steps for Using SRCs

Step 1: Apply to use SRCs to satisfy Offv 30 days in advance of final construction inspection.

Step 2: Receive DDOE approval of use of SRCs.

Step 3: Schedule final construction inspection with DDOE (Steps 2 and 3 can be reversed).

Step 4: Pass final construction inspection and start use of SRCs.

Step 5: 30 days before SRC expiration, apply to use additional SRCs to satisfy Offv.

Step 6: Receive DDOE approval of use of SRCs.

Step 7: Repeat Steps 5 and 6 as necessary.

6.3 Off-Site Retention via In-Lieu Fee

In-lieu fee corresponds to one gallon of retention for one year. Payment of one gallon worth of in-lieu fee satisfies one gallon of Off-Site Retention Volume (Offv) for one year. A regulated site may elect to install additional BMPs on site in a sufficient volume to eliminate or reduce the Offv.

To use in-lieu fee to meet an Offv, a regulated site must submit payment to the District, along with a notification form (see Appendix C). The notification and payment may be for multiple years. The notification and payment must be submitted 30 days in advance of the planned date of use. In-lieu fee (and/or SRCs) must be in use as of the successful completion of DDOE's final inspection at the end of the construction process and thereafter on an ongoing basis.

DDOE will confirm receipt of in-lieu fee. DDOE will not sign off on a regulated site's final inspection at the end of the construction process until it has verified that its Offv is achieved. The one-year lifespan of the in-lieu fee begins as of the date that it is used to meet Offv.

If DDOE does not receive an application to use SRCs or an in-lieu fee payment and a lapse in compliance with an Offv occurs, DDOE shall charge an in-lieu fee, with a 10 percent late fee, to the regulated site owner and provide notice to the site owner accordingly. For a site owner who does not comply within 30 days of DDOE's notice of a lapse in satisfaction of an Offv obligation and who owns an SRC that has not been used to satisfy the Offv for another site, DDOE may apply that SRC to the Offv that is out of compliance. DDOE may also take enforcement action against a regulated site that fails to comply with an Offv.

6.4 Forms for Use of Off-site Retention

See Appendix C for the following forms for use by the applicant:

- Application to Use Stormwater Retention Credits for Off-Site Retention Volume
- Notification of In-Lieu Fee Payment

Chapter 7 Generation, Certification, Trading, and Retirement of Stormwater Retention Credits

7.1 Stormwater Retention Credits Overview

This chapter provides details on the eligibility requirements for certification of Stormwater Retention Credits (SRCs); the administrative process for certifying SRCs; the format for SRC serial numbers; the consequences for failure to maintain SRC-generating retention capacity; buying and selling SRCs; and voluntary retirement of SRCs. The chapter also explains how to calculate SRCs using DDOE's SRC Calculator and provides some example calculations.

The following background, covered elsewhere in this Guidebook and the regulations, may be helpful in reviewing this chapter:

- One Stormwater Retention Credit (SRC) is equal to one gallon of retention for one year.
- One SRC can be used by a major regulated project to achieve one gallon of its Off-Site Retention Volume (Offv) for one year.
- The clock starts on an SRC's one-year lifespan when it is used to satisfy an Offv.
- An unused SRC can be banked for future use without expiring.
- An SRC can be traded.
- An SRC can be voluntarily retired without being used.

7.2 Eligibility Requirements

DDOE will certify Stormwater Retention Credits (SRCs) for eligible stormwater best management practices (BMPs) and land cover in the District of Columbia. To be eligible, the retention capacity in a BMP or land cover must do the following:

- Achieve retention volume in excess of regulatory requirements, but less than the SRC ceiling;
- For unregulated projects or voluntary stormwater retrofits, achieve retention volume in excess of preproject retention but less than the SRC ceiling;
- Be designed and installed in accordance with a DDOE-approved Stormwater Management Plan (SWMP) and the Stormwater Management Guidebook;
- Pass a post-construction inspection and ongoing maintenance inspections; and
- Provide a maintenance contract or maintenance agreement(s) for ongoing maintenance.

In addition, retention capacity installed must have been installed after May 1, 2009 in order to be eligible.

7.2.1 Eligibility Requirements: Retention Volume

To be eligible, retention capacity must achieve retention in excess of stormwater management regulatory requirements or, for unregulated sites, in excess of preproject retention.

For sites required to achieve a Stormwater Retention Volume (SWRv), eligible retention volume is the volume achieved in excess of the SWRv, but less than the SRC ceiling as shown in Figure 7.1.

For sites required to treat a water quality treatment volume (prior to establishment of SWRv requirements), eligible retention volume is the volume retained in excess of the stormwater treatment requirements in place at that time. For example, for a regulated site that provided treatment for the 0.5-inch storm by installing BMPs capable of retaining the 0.9-inch storm, the eligible retention volume would be the difference between the 0.9-inch storm volume and the 0.5-inch storm volume (i.e., 0.4-inch storm volume).

For sites that are unregulated or that would only trigger the regulations because of the voluntary installation of retention capacity, eligible retention volume is the volume achieved in excess of preproject on-site retention, as shown in Figure 7.1.

Guidance on calculating volume eligibility of retention capacity for certification of SRCs is below, and an SRC calculation spreadsheet is available on DDOE’s website.

In all cases, DDOE shall not certify SRCs for retention capacity in excess of the runoff volume expected to occur from a 1.7 inch rainfall event (“SRC Ceiling”) (see Figure 7.1),

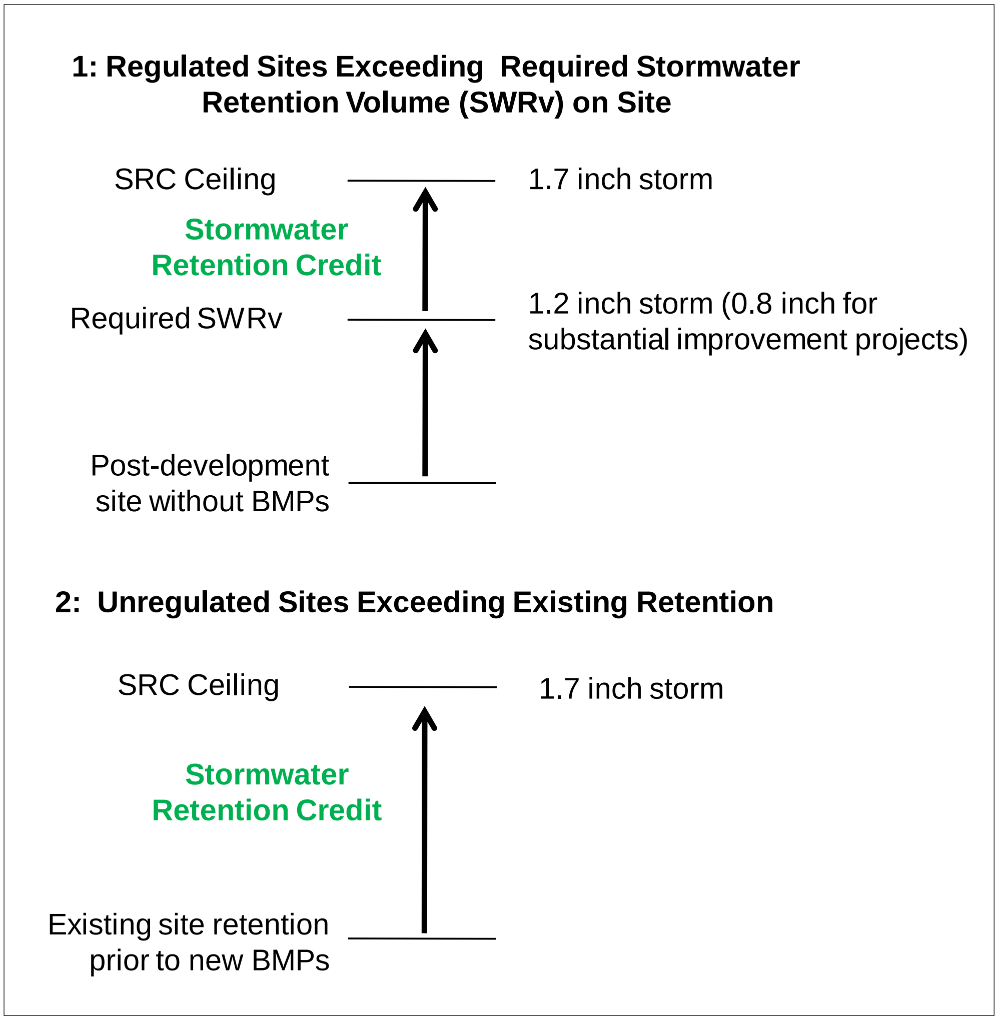


Figure 7.1 Retention volume eligible to earn SRCs.

7.2.2 Eligibility Requirements: Design and Installation

To be eligible for SRC certification, retention BMPs or land covers must be designed and installed according to a DDOE-approved SWMP, with an as-built SWMP submitted to DDOE.

DDOE recognizes that some retention capacity, voluntarily installed prior to the establishment of retention standards, was installed without obtaining DDOE approval of a SWMP prior to installation. This retention capacity may still be eligible to earn SRCs. In such cases, DDOE will require an as-built SWMP stamped by a professional engineer licensed in the District of Columbia, as well as documentation of existing site conditions prior to the installation of the retention capacity. DDOE will consider such Applications for Certification of SRCs on a case-by-case basis and will determine eligible retention capacity in accordance with the specifications in this Stormwater Management Guidebook.

7.2.3 Eligibility Requirements: Inspection

To be eligible for SRC certification, retention BMPs and land covers must pass DDOE's post-construction inspection and continue to pass inspections on an ongoing basis. DDOE typically inspects BMPs every three years but may also conduct unscheduled inspections of retention capacity, on a random basis or as a result of a potential problem that is identified by DDOE or the public.

7.2.4 Eligibility Requirements: Maintenance

To be eligible for SRC certification, retention capacity must be maintained in good working order, as specified by DDOE. In an application for certification of SRCs, the proposed SRC owner (who becomes the original SRC owner once DDOE certifies the SRCs) signs a statement swearing to maintain the retention capacity for the period of time for which SRC certification is requested. To demonstrate the commitment to maintenance, the applicant must submit a current maintenance contract for the time period for which SRC certification is requested. Alternatively, applicants may conduct this maintenance, but they must demonstrate that they have the expertise and capacity to conduct the maintenance. The applicant shall submit the maintenance contract or other documentation of expertise and capacity as an attachment to the application for certification of SRCs.

7.3 Certification of Stormwater Retention Credits

DDOE will accept applications for certification of SRCs once the regulations related to certification and ownership of SRCs are finalized in the *D.C. Register*. Required supporting documentation for the initial application includes the completed SRC calculation spreadsheet, as-built SWMP, and signed maintenance agreement or contract. Applications for retention capacity installed without prior DDOE approval of a SWMP must also provide documentation of site conditions prior to installation, including land cover type and existing retention BMPs. (See Chapter 2 and Appendix A for Stormwater Retention Volume calculations.)

Appendix D contains the application form for certification of SRCs. Through the form, DDOE receives information that is necessary to track and record generated SRCs. Such information includes the address of the site with eligible retention capacity, the owner of proposed SRCs, and the owner's agent, among other information. Applicants should note the format for submitting information on the drainage areas and BMPs that will generate SRCs on a site. Applicants should assign each drainage area a letter (e.g., A, B, C) and each BMP a corresponding number (e.g., A1, B2, C3).

DDOE will review the application and supporting documentation to make a determination as to the number of SRCs to certify. DDOE will send its response to the proposed SRC owner who is listed on the application for certification. DDOE expects that the proposed SRC owner would very often be both the owner of the retention capacity and the owner of the property, but recognizes that this may not always be the case. If the proposed SRC owner is not the property owner, the proposed SRC owner must include documentation of the right to own the SRC applied for.

DDOE will certify up to three years' worth of SRCs for eligible retention capacity (the three-year period is based on DDOE's typical three-year inspection cycle). DDOE will assign each SRC a unique serial number for tracking purposes. At the end of that three-year period, the owner may apply for another three years' worth of SRCs. For example, for 1,000 gallons of eligible retention capacity, DDOE will certify up to 3,000 SRCs initially and an additional 3,000 SRCs at the beginning of each subsequent three-year period, as long as the eligibility requirements continue to be met.

An applicant should only apply for certification of SRCs corresponding to the period for which maintenance is planned. In applying for SRCs, an applicant commits to the maintenance of the retention capacity for the time period for which SRC certification is requested. Failure to maintain SRC-generating retention capacity is discussed below.

An applicant who wishes to have SRCs certified after the initial period of certification shall re-submit an application for certification of SRCs. The required supporting documentation for this re-submittal is a current maintenance contract or documentation of ongoing expertise and capacity to conduct the maintenance. DDOE expects to issue additional SRCs for retention capacity that has passed re-inspection and for which a submitted the commitment to maintain has been demonstrated.

Key Milestones for the Generation of SRCs:

1. Receive DDOE approval of proposed SWMP.
2. Install BMPs and/or land covers.
3. Pass DDOE's post-construction inspection.
4. Submit application for DDOE certification of SRCs, including:
   (a) As-built SWMP;
   (b) Current maintenance contract or documentation of expertise and capacity to conduct maintenance; and
   (c) Documentation of the legal right to the SRCs applied for, if the proposed SRC owner is not the property owner.
5. Receive DDOE certification for up to three years' worth of SRCs.
6. Maintain retention capacity and pass subsequent inspections.*
7. Submit application for DDOE certification of SRCs, including:
   (a) Current maintenance contract or documentation of expertise and capacity to conduct maintenance and.
   (b) Documentation of the legal right to the SRCs applied for, if the proposed SRC owner is not the property owner.*
8. Receive DDOE certification for up to three years' worth of additional SRCs.*

*Steps 6, 7, and 8 can be repeated indefinitely

7.4 Format of SRC Serial Numbers

RC serial numbers are based on the following format:

Beginning of certification year (yyyymmdd)	-	Major and Sub drainage (A,R,P and 2 digits)	-	SWMP number (5 digits)	-	Individual gallon of capacity (6 digits)

For example, a proposed SRC owner submits a complete application for certification of SRCs on January 1, 2014 for 1,000 gallons of eligible retention capacity located in the Watts Branch sub-drainage of the Anacostia River. The retention capacity was installed in accordance with a DDOE-approved SWMP with “1400” as the identification number. After approving the application for three years’ worth of SRCs, DDOE would issue 3,000 SRCs as follows:

1,000 SRCs *20140101-A19-01400-000001 - 20140101-A19-01400-001000*

1,000 SRCs *20150101-A19-01400-000001 - 20150101-A19-01400-001000*

1,000 SRCs *20160101-A19-01400-000001 - 20160101-A19-01400-001000*

This example assumes Watts Branch has been assigned “19” as an identifying number, but the numbering of sub-drainages has not been finalized. When the list of each sub-drainage’s identifying number is final, DDOE will post it on its website.

7.5 Failure to Maintain Retention after Certification of Stormwater Retention Credits

Sites need not file a declaration of covenants for the maintenance of retention capacity for which DDOE has certified SRCs. However, DDOE will not certify additional SRCs for retention capacity that is not maintained. Furthermore, original SRC owners will be required to compensate for the associated retention failure during the time period for which maintenance did not occur by doing one of the following: 1) forfeiting those SRCs (if they have not been sold or used); 2 purchasing replacement SRCs that DDOE will then retire; or 3) paying in-lieu fee to DDOE.

7.6 Buying and Selling Stormwater Retention Credits

Each SRC has a unique serial number, and DDOE will track the ownership and use of each SRC. Before the ownership of an SRC can be officially transferred, DDOE must approve a completed application for transfer of SRC ownership in order to verify the ownership and status of the SRCs. The new owner of the SRCs cannot use the SRCs to meet an Offv until DDOE has approved the application.

SRCs can be banked for future use without expiring. The one-year lifespan of an SRC begins once it is used to achieve an Offv.

Key Milestones in Transfer of SRC Ownership

1. Negotiate terms of transfer/contract between buyer and seller.
2. Submit application for transfer of SRC ownership to DDOE.
3. Receive DDOE confirmation of transfer of SRC ownership.

7.7 Voluntary Retirement of Stormwater Retention Credits

An SRC owner can request that an SRC be retired by submitting an application to retire SRCs.

7.8 Quitting the Obligation to Maintain Retention for Stormwater Retention Credits

An original SRC owner can quit the obligation to maintain retention capacity for which an SRC is certified. If the SRC has not been sold or used to satisfy an Offv, the owner may submit an application to retire the SRC. If the SRC was sold or used, the original owner may request that DDOE retire another SRC in its place or pay the in-lieu fee to compensate.

7.9 Calculation of Stormwater Retention Credits

A person should use DDOE's SRC calculator spreadsheet, available on DDOE's website, to calculate the retention capacity on a site that meets the retention volume eligibility requirement. As discussed above, retention capacity must also meet eligibility requirements for design and installation; inspection; and maintenance in order for DDOE to certify SRCs.

Use of the SRC calculator spreadsheet is discussed below. The calculator allows SRC calculation for multiple drainage areas on a site.

Note that major regulated projects that are interested in exceeding the required SWRv in order to generate SRCs should input data in the SRC calculator's Existing Retention section based on the proposed site conditions upon achievement of the SWRv. Any changes to land cover and retention above and beyond the SWRv should be input in the Proposed Retention section. Scenario 3 in Section 7.9 is an example of a major regulated project that exceeds the SWRv in order to generate SRCs.

On the SRC calculator spreadsheet, cells highlighted in blue are user input cells. Cells highlighted in gray are calculation cells, and cells highlighted in yellow are constant values.

The steps given below are meant to be followed while working with DDOE's SRC calculator spreadsheet. Note that **only entry of input data is required by users**—no manual calculations are required except when more than 4 BMPs are present or proposed in each drainage area for Steps 1(c) and 2(c) (adding up BMP retention). The equations utilized in the spreadsheet are given below for informational purposes.

Step 1: Determine Preproject Retention for Drainage Area 1.

a. Input area of each preproject land cover, including Impervious Cover, Compacted Cover, and Natural Cover in **lines 14–16**. Guidance for various land covers is provided in Appendix N and Table A.1 of Appendix A.

b. Automatic calculation of retention provided by preproject land cover. This is equivalent to the abstraction provided by the land, determined by modifying the formula for calculating the SWRv. The calculation applies a retention coefficient (0.05 for Impervious Cover, 0.75 for Compacted Cover, and 1.0 for Natural Cover) to each of the land cover areas, using the 1.7-inch storm depth. (**line 17**).

$$ER_{LC} = (0.05 \times EIA + 0.75 \times ECCA + 1.0 \times ENA) \times \frac{PC}{12} \times 7.48$$

where:

ER_{LC} = retention from the existing (preproject) land cover (gal) (**line 17**)
EIA = existing (preproject) impervious cover area (ft^2) (**line 14**)
$ECCA$ = existing (preproject) compacted cover area (ft^2) (**line 15**)
EN = existing (preproject) natural cover area (ft^2) (**line 16**)
PC = precipitation ceiling (in.) (**line 10**)

c. Input each existing retention BMP in **lines 20–23**. If there are more than four existing BMPs, sum the additional BMP retention volumes (for example, BMP 4 + BMP 5 + BMP 6 + …) by drainage area in the last row (**line 23**).

d. Automatic calculation of the total existing retention as sum of existing retention by land (**line 17**) and existing retention by BMPs (**lines 20 through 23**). (**line 25**).

$$ER_T = ER_{LC} + ER_{P1} + ER_{P2} + ER_{P3} + ER_{P4,5,6,etc.}$$

where:

ER_T = total existing (preproject) retention (gal) (line 25)
ER_{LC} = retention from the existing (preproject) land cover (gal) (**line 17**)
ER_{P1} = retention from first existing (preproject) BMP (gal) (**line 20**)
ER_{P2} = retention from second existing (preproject) BMP (gal) (**line 21**)
ER_{P3} = retention from third existing (preproject) BMP (gal) (**line 22**)
$ER_{P4,5,6,etc.}$ = retention from third existing (preproject) BMP (gal) (**line 23**)

Step 2: Determine Proposed Retention for Drainage Area 1.

a. Input the proposed land cover including Impervious Cover, Compacted Cover, and Natural Cover in **lines 28-30**. Guidance for various land covers is provided in Table A.1 and Appendix N.

b. Automatic calculation of retention provided by proposed land cover. This is equivalent to the abstraction provided by the land, determined by modifying the formula for calculating the SWRv. The calculation applies a retention coefficient (0.05 for Impervious Cover, 0.75 for compacted cover, and 1.0 for natural cover) to each of the land cover areas, using the 1.7-inch storm depth. (**line 31**).

$$PR_{LC} = (0.05 \times PIA + 0.75 \times PCCA + 1.0 \times PNA) \times \frac{PC}{12} \times 7.48$$

where:

PR_{LC}	=	retention from the proposed land cover (gal) (**line 31**)
PIA	=	proposed impervious cover area (ft^2) (**line 28**)
$PCCA$	=	proposed compacted cover area (ft^2) (**line 29**)
PNA	=	proposed natural cover area (ft^2) (**line 30**)
PC	=	precipitation ceiling (in.) (**line 10**)

c. Input each proposed retention BMP in **lines 34-37**. If there are more than four existing BMPs, sum the additional BMP retention volumes (for example, BMP 4 + BMP 5 + BMP 6 + …) by drainage area in the last row (**line 37**).

d. Automatic calculation of the total proposed retention as a sum of proposed retention by land (**line 31**) and proposed retention by BMPs (**lines 34 through 37**). (**line 39**).

$$PR_T = PR_{LC} + PR_{P1} + PR_{P2} + PR_{P3} + PR_{P4,5,6,etc.}$$

where:

PR_T	=	total proposed retention (gal) (**line 39**)
PR_{LC}	=	retention from the proposed land cover (gal) (**line 31**)
PR_{P1}	=	retention from first proposed BMP (gal) (**line 34**)
PR_{P2}	=	retention from second proposed BMP (gal) (**line 35**)
PR_{P3}	=	retention from third proposed BMP (gal) (**line 36)**
$PR_{P4, 5, 6, etc.}$	=	retention from third proposed BMP (gal) (**line 37**)

Step 3: **Calculate SRCs for Drainage Area 1.**

Automatic calculation of SRC-eligible volume. The total preproject retention (**line 25**) is subtracted from the total proposed retention (**line 39**) providing an initial calculation of SRCs in **line 42**.

$$PAR_T = PR_T - ER_T$$

where:

PAR_T	=	proposed additional retention (gal) (**line 42**)
PR_T	=	total proposed retention (gal) (**line 39**)
ER_T	=	total existing (preproject) retention (gal) (**line 25**)

Step 4: Verify SRC-Eligible Volume Against Maximum Allowable for Drainage Area 1.

a. Automatic calculation of $SRC_{Ceiling}$, based on runoff from preproject land cover, with P = 1.7 inches (**line 45**).

$$SRC_{Ceiling} = (0.95 \times EIA + 0.25 \times ECCA + 0 \times ENA) \times \frac{PC}{12} \times 7.48$$

where:

$SRC_{Ceiling}$	=	Stormwater Retention Credit ceiling (gal) (**line 45**)
EIA	=	existing (preproject) impervious cover area (ft^2) (**line 14**)
$ECCA$	=	existing (preproject) compacted cover area (ft^2) (**line 15**)
ENA	=	existing (preproject) natural cover area (ft^2) (**line 16**)
PC	=	precipitation ceiling (in.) (**line 10**)

b. Automatic calculation of maximum allowable number of SRCs. SRCs shall not exceed maximum allowable SRCs, as defined by the difference between the SRC Ceiling and the sum of Preproject BMP Retention (**line 46**).

$$SRC_{Maximum} = SRC_{Ceiling} - (ER_{P1} + ER_{P2} + ER_{P3} + ER_{P4,5,6,etc.})$$

where:

$SRC_{Maximum}$	=	maximum Stormwater Retention Credit allowable (gal) (**line 46**)
$SRC_{Ceiling}$	=	Stormwater Retention Credit ceiling (gal) (**line 45**)
ER_{P1}	=	retention from first existing (preproject) BMP (gal) (**line 20**)
ER_{P2}	=	retention from second existing (preproject) SBMP (gal) (**line 21**)
ER_{P3}	=	retention from third existing (preproject) BMP (gal) (**line 22**)
$ER_{P4, 5, 6, etc.}$	=	retention from third existing (preproject) BMP (gal) (**line 23**)

c. Automatic output of SRC-eligible volume for drainage area 1 by comparing initial calculation of SRCs against maximum allowable (**line 48**).

if:

$$PAR_T < SRC+\text{, then } SRC_{Eligible} = PAR_T$$

otherwise:

$$SRC_{Eligible} = SRC_{Maximum}$$

where:

$SRC_{Eligible}$	=	eligible Stormwater Retention Credit (gal) (**line 48**)
$SRC_{Maximum}$	=	maximum Stormwater Retention Credit Allowable (gal) (**line 46**)
PAR_T	=	proposed additional retention (gal) (**line 42**)

Step 5: **Repeat Steps 1–4 for Each Applicable Drainage Area.**

Five drainage area columns are provided. Sites with more than five drainage areas will require additional spreadsheets.

Step 6: **Total SRC-Eligible Volume.**

Automatic calculation of the total eligible SRC gallons for the site by summing SRC-eligible volume for each drainage area in **line 50**.

$$SRC_{Eligible-Site} = SRC_{Eligible-A} + SRC_{Eligible-B} + SRC_{Eligible-C} + SRC_{Eligible-D}$$

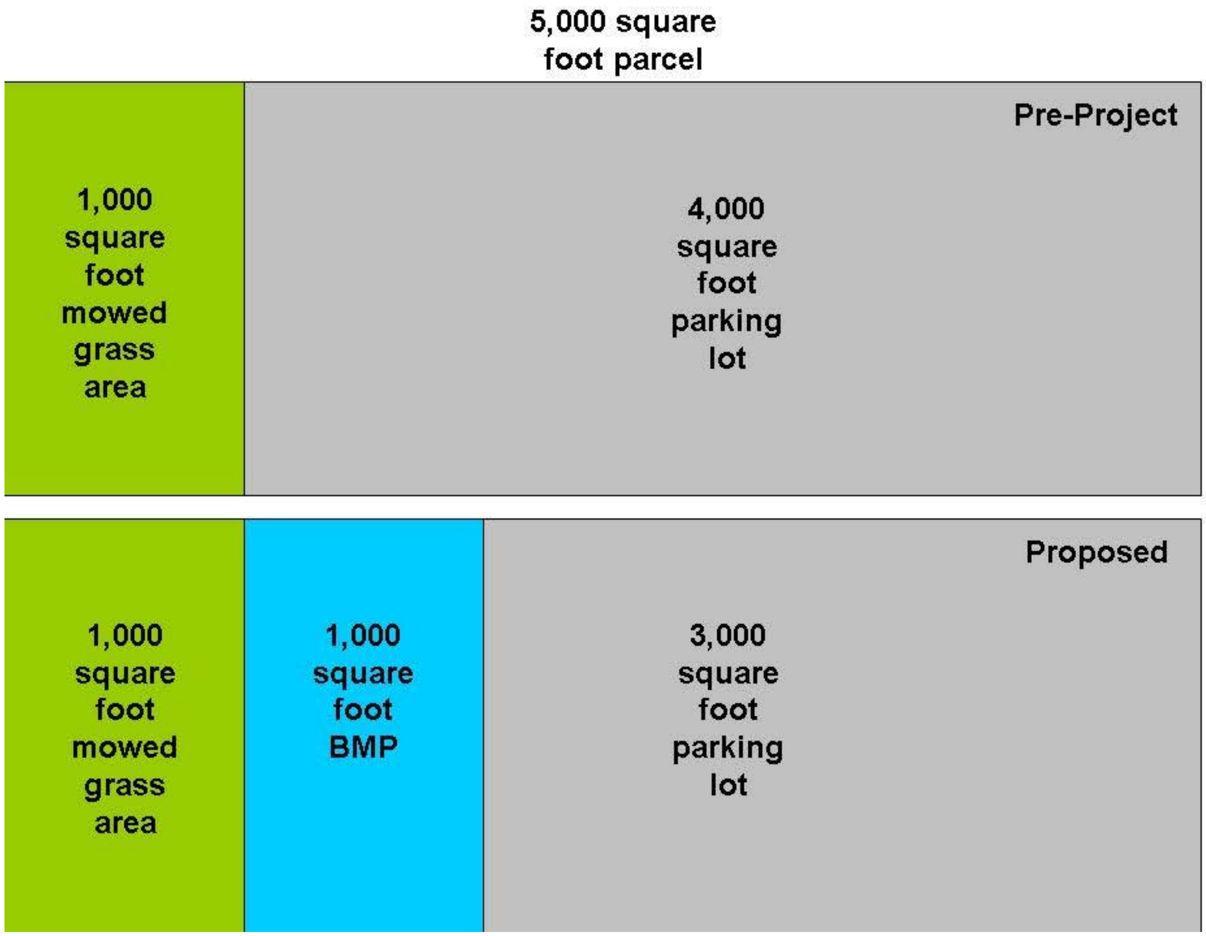
where:

$SRC_{Eligible\text{-}Site}$	=	total eligible SRC for the entire site (gal) (**line 50**)
$SRC_{Eligible\text{-}A}$	=	total eligible SRC for Drainage Area 1 (gal) (**line 48**)
$SRC_{Eligible\text{-}B}$	=	total eligible SRC for Drainage Area 2 (gal) (**line 48**)
$SRC_{Eligible\text{-}C}$	=	total eligible SRC for Drainage Area 3 (gal) (**line 48**)
$SRC_{Eligible\text{-}D}$	=	total eligible SRC for Drainage Area 4 (gal) (**line 48**)

7.10 Stormwater Retention Credit Calculation Scenarios

Scenario 1

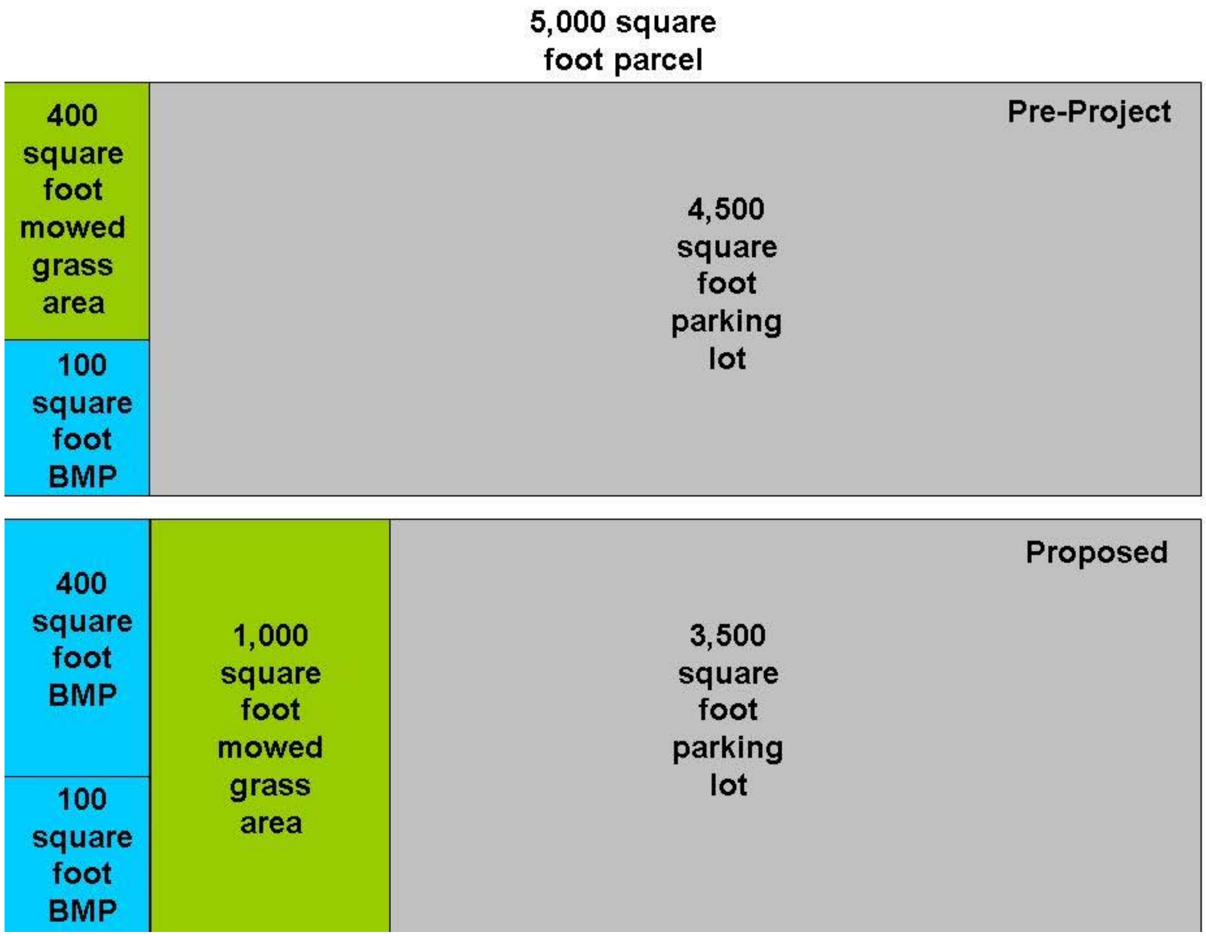
The site has a single drainage area. The parcel is a 5,000-square foot rectangle. There are two land covers on the site: a 4,000-square foot parking lot and an adjacent 1,000-square foot grass area that is regularly mowed. The parking lot is defined as impervious surface and the mowed grass area is defined as compacted cover. The owner contemplates converting 1,000 square feet of parking surface into a bioretention, which is defined as impervious. Using Chapter 3.5 Bioretention, the proposed BMP is designed to retain 1,500 gallons of runoff from the parking lot.


5,000 square foot parcel
Pre-Project
1,000 square foot mowed grass area
4,000 square foot parking lot
Proposed
1,000 square foot mowed grass area
1,000 square foot BMP
3,000 square foot parking lot

Step 1: Pre-Project Retention	Drainage Area A	B	C	D	E
Impervious Area (ft²)	4,000	0	0	0	0
Compacted Cover Area (ft²)	1,000	0	0	0	0
Natural Area (ft²)	0	0	0	0	0
Retention from Pre-Project Land Cover (gal)	1,007	0	0	0	0
Retention from Pre-Project Best Management Practice (BMP)					
BMP 1 (gal)	0	0	0	0	0
BMP 2 (gal)	0	0	0	0	0
BMP 3 (gal)	0	0	0	0	0
Add together BMP 4, 5, 6, etc.(gal)	0	0	0	0	0
Total Pre-Project Retention (gal)	1,007	0	0	0	0
Step 2: Proposed Retention					
Impervious Area (ft²)	4,000	0	0	0	0
Compacted Cover Area (ft²)	1,000	0	0	0	0
Natural Area (ft²)	0	0	0	0	0
Retention from Proposed Land Cover (gal)	1,007	0	0	0	0
Retention from Proposed BMP - include BMPs retained from pre-project conditions					
BMP 1 (gal)	1,500	0	0	0	0
BMP 2 (gal)	0	0	0	0	0
BMP 3 (gal)	0	0	0	0	0
Add together BMP 4, 5, 6, etc.(gal)	0	0	0	0	0
Total Proposed Retention (gal)	2,507	0	0	0	0
Step 3: Calculate SRCs (internal calculation)					
Total Additional Retention Proposed	1,500	0	0	0	0
Step 4: Verify SRCs (internal calculation)					
SRC Ceiling	4,292	0	0	0	0
Maximum SRCs (based on Pre-Project BMP)	4,292	0	0	0	0
SRC Eligible Volume (gal)	1,500	0	0	0	0
Site Total SRC Eligible Volume (gal)	**1,500**				

Scenario 2

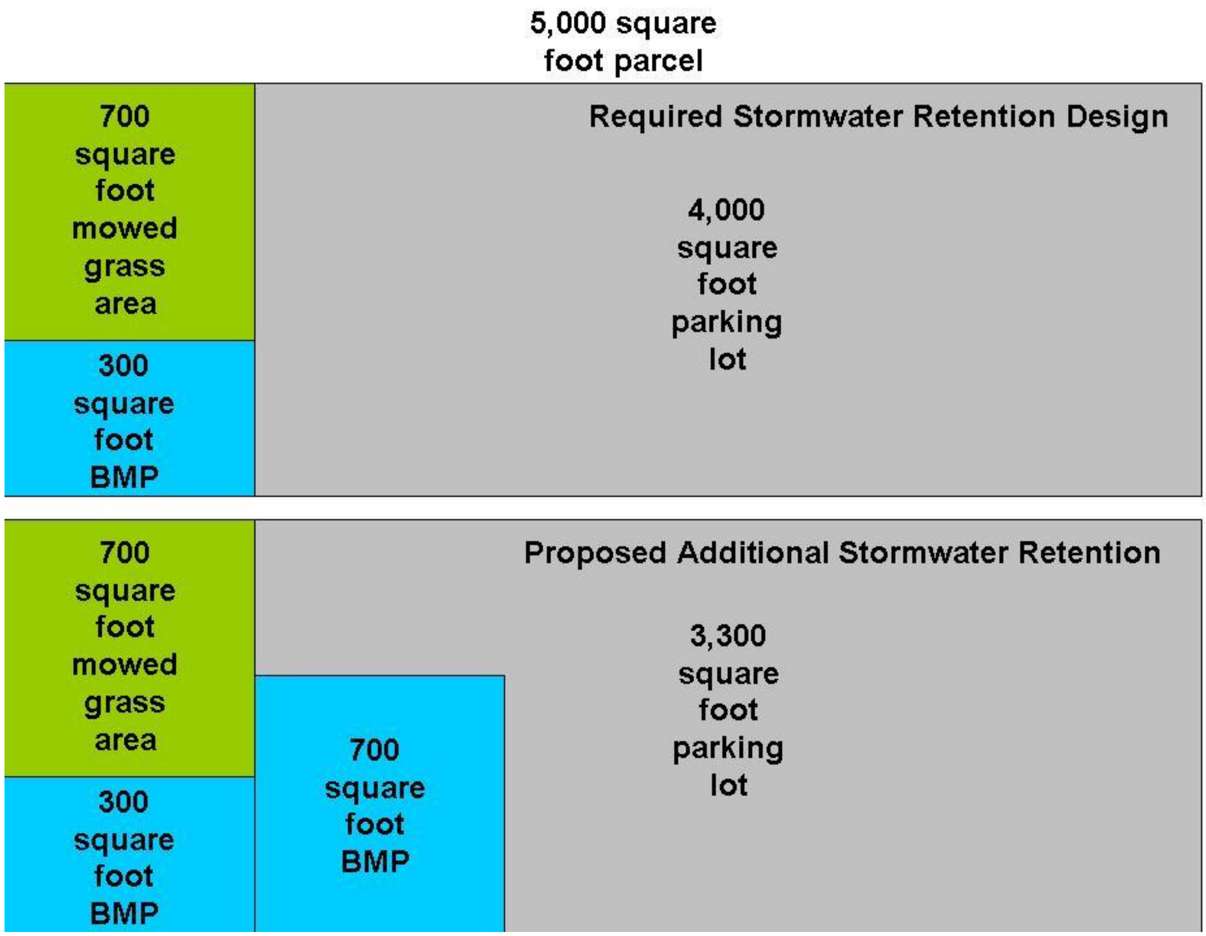
The site has a single drainage area. The parcel is a 5,000-square foot rectangle and is divided between a 4,500-square foot parking lot and an adjacent 400-square foot grass area that is regularly mowed. There is an existing bioretention (the land areas of all BMPs are considered impervious) covering 100 square feet and determined to retain 1,000 gallons using Chapter 3.5. The parking lot is defined as impervious surface and the mowed grassy area is defined as compacted cover. The owner contemplates converting the grass area into bioretention and reducing the parking lot size by 1,000 square feet, with that area converted into mowed grass. Using Chapter 3.5 Bioretention, the proposed 400-square foot BMP is designed to retain 1,500 gallons of runoff from the parking lot in addition to the 1,000 gallons retained by the original BMP.



	Drainage Area				
Step 1: Pre-Project Retention	A	B	C	D	E
Impervious Area (ft²)	4,600	0	0	0	0
Compacted Cover Area (ft²)	400	0	0	0	0
Natural Area (ft²)	0	0	0	0	0
Retention from Pre-Project Land Cover (gal)	562	0	0	0	0
Retention from Pre-Project Best Management Practice (BMP)					
BMP 1 (gal)	1,000	0	0	0	0
BMP 2 (gal)	0	0	0	0	0
BMP 3 (gal)	0	0	0	0	0
Add together BMP 4, 5, 6, etc.(gal)	0	0	0	0	0
Total Pre-Project Retention (gal)	1,562	0	0	0	0
Step 2: Proposed Retention					
Impervious Area (ft²)	4,000	0	0	0	0
Compacted Cover Area (ft²)	1,000	0	0	0	0
Natural Area (ft²)	0	0	0	0	0
Retention from Proposed Land Cover (gal)	1,007	0	0	0	0
Retention from Proposed BMP - include BMPs retained from pre-project conditions					
BMP 1 (gal)	1,000	0	0	0	0
BMP 2 (gal)	1,500	0	0	0	0
BMP 3 (gal)	0	0	0	0	0
Add together BMP 4, 5, 6, etc.(gal)	0	0	0	0	0
Total Proposed Retention (gal)	3,507	0	0	0	0
Step 3: Calculate SRCs (internal calculation)					
Total Additional Retention Proposed	1,945	0	0	0	0
Step 4: Verify SRCs (internal calculation)					
SRC Ceiling	4,737	0	0	0	0
Maximum SRCs (based on Pre-Project BMP)	3,737	0	0	0	0
SRC Eligible Volume (gal)	1,945	0	0	0	0
Site Total SRC Eligible Volume (gal)	**1,945**				

Scenario 3

The site is a proposed development with land disturbance activities that trigger the stormwater regulation. We limit the scenario to one of several drainage areas within the project's limits of disturbance. The drainage area is 5,000 square feet. It will contain a newly constructed 4,000-square foot parking lot and an adjacent existing 700-square foot grass area that is regularly mowed. A proposed bioretention will manage parking lot runoff and cover 300 square feet. This bioretention will retain 3,186 gallons based on Chapter 3.5. In this scenario, these gallons are the regulated Stormwater Retention Volume (SWRv) for this drainage area. The parking lot and the bioretention are defined as impervious surface, and the mowed grass area is defined as compacted cover. The owner contemplates converting 700 square feet of parking lot into bioretention to gain additional retention gallons above the regulatory obligation. Using Chapter 3.5 Bioretention, the additional 700 square feet will provide 3,000 gallons of additional retention.



	Drainage Area				
Step 1: Pre-Project Retention	A	B	C	D	E
Impervious Area (ft²)	4,300	0	0	0	0
Compacted Cover Area (ft²)	700	0	0	0	0
Natural Area (ft²)	0	0	0	0	0
Retention from Pre-Project Land Cover (gal)	784	0	0	0	0
Retention from Pre-Project Best Management Practice (BMP)					
BMP 1 (gal)	3,186	0	0	0	0
BMP 2 (gal)	0	0	0	0	0
BMP 3 (gal)	0	0	0	0	0
Add together BMP 4, 5, 6, etc.(gal)	0	0	0	0	0
Total Pre-Project Retention (gal)	3,970	0	0	0	0
Step 2: Proposed Retention					
Impervious Area (ft²)	4,300	0	0	0	0
Compacted Cover Area (ft²)	700	0	0	0	0
Natural Area (ft²)	0	0	0	0	0
Retention from Proposed Land Cover (gal)	784	0	0	0	0
Retention from Proposed BMP - include BMPs retained from pre-project conditions					
BMP 1 (gal)	3,186	0	0	0	0
BMP 2 (gal)	3,000	0	0	0	0
BMP 3 (gal)	0	0	0	0	0
Add together BMP 4, 5, 6, etc.(gal)	0	0	0	0	0
Total Proposed Retention (gal)	6,970	0	0	0	0
Step 3: Calculate SRCs (internal calculation)					
Total Additional Retention Proposed	3,000	0	0	0	0
Step 4: Verify SRCs (internal calculation)					
SRC Ceiling	4,514	0	0	0	0
Maximum SRCs (based on Pre-Project BMP)	1,328	0	0	0	0
SRC Eligible Volume (gal)	1,328	0	0	0	0
Site Total SRC Eligible Volume (gal)	**1,328**				

7.11 Forms for Stormwater Retention Credits

See Appendix D for the following forms for use by the applicant:

- Application for Certification of Stormwater Retention Credits
- Application for Transfer of Stormwater Retention Credit Ownership
- Application to Retire Stormwater Retention Credits