Chapter 4 Stormwater Best Management Practices (BMPs)

Standard Stormwater BMP Design Sections

This chapter summarizes and outlines performance criteria for 13 stormwater best management practice (BMP) categories that include:

- Bioretention
- Permeable Pavements
- Infiltration
- Green Roofs
- Rainwater Harvesting
- Impervious Surface Disconnection
- Open Channel Systems
- Filtering Systems
- Storage Practices
- Ponds
- Stormwater Wetlands
- Tree Planting and Preservation
- Proprietary Practices

Following these criteria is the criteria to credit for stormwater benefit the use of conservation areas and open space preservation.

Format of Standard Stormwater BMP Design Sections

BMP performance criteria are based on several critical design factors to ensure effective and long-lived BMPs.

For each BMP, the following factors are discussed:

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

Design components that differ from these specifications, but meet their intent, may be included at <*local jurisdiction*>'s discretion.

Standard Nomenclature

In this chapter, and throughout the guidebook, the terms, *must* or *shall*, denote required aspects of BMPs or their design and implementation. The term, *should*, denotes a recommendation, however, justification may be necessary for design or implementation that does not correspond to certain recommendations.

Summary of BMPs Stormwater Management Capabilities, Site Applicability, and Site Conditions/Physical Feasibility

Stormwater management requirements for a given site vary based on the site's location, and minimum control requirements discussed in detail in Section 3.5.

Stormwater Retention and Water Quality Treatment

It is important to note that this Manual, and the associated compliance calculators, make a distinction between stormwater retention volume and stormwater water quality treatment. Not all BMPs achieve stormwater retention and/or water quality treatment equally, as was summarized in Table 3.3. The level to which a BMP provides stormwater retention and water quality treatment is provided in the BMP summary table of each BMP. The stormwater retention value (SWRv) rates are expressed as a percentage of the storage volume provided by the BMP. Calculations for determining storage volume are included in each BMP's specifications. Each BMP's performance on the water quality parameters of total suspended solids, nitrogen and bacteria are also included in the BMP summary table. Note that many BMPs whose main purpose is water quality treatment typically do not have enough volume control to manage larger storm events.

Site Applicability

Certain BMPs are more appropriate than others in certain land uses. Table 0.1 describes the site applicability for each BMP for the following factors:

Rural Use: This column indicates whether or not the stormwater management practice is typically suited for use in rural areas and on low-density development sites.

Suburban Use: This column indicates whether or not the stormwater management practice is typically suited for use in suburban areas and on medium-density development sites.

Urban Use: This column identifies the stormwater management practices that are typically suited for use in urban and ultra-urban areas where space is at a premium.

Construction Cost: This column assesses the relative construction cost of each of the stormwater management practices.

Maintenance: This column assesses the relative maintenance burden associated with each stormwater management practice. Note that all stormwater management practices require routine inspection and maintenance.

Table 0.1 Site Applicability for BMPs

BMP	Rural Use	Suburban Use	Urban Use	Construction Cost	Maintenance
Bioretention	Yes	Yes	Yes	Medium	Medium
Permeable Pavement	Maybe	Yes	Yes	High	High
Infiltration	Yes	Yes	Yes	Medium	Medium
Green Roof	Maybe	Yes	Yes	High	Low
Rainwater Harvesting	Yes	Yes	Yes	Medium	Medium
Disconnection	Yes	Yes	Maybe	Low	Low
Open Channels	Yes	Yes	No	Low-Medium	Medium

Filtration	Maybe	Yes	Yes	High	High
Dry Ponds	Yes	Yes	No	Low	Low
Wet Ponds	Yes	Yes	No	Low	Low
Stormwater Wetlands	Yes	Yes	No	Low	Medium

Site Conditions/Physical Feasibility

While some BMPs can be applied almost anywhere, others require specific conditions to be most effective. Physical feasibility refers to the physical site conditions necessary to effectively design and install a BMP. Table 0.2 includes the feasibility factors listed below.

Contributing Drainage Area (CDA): Volume of water received by a practice can affect BMP performance. This column indicates the contributing drainage areas that typically apply for each BMP.

Slope: This column describes the influence that site slope can have on the performance of the BMP. It indicates the maximum or minimum slope on which the BMP should be installed.

Minimum Head: This column provides an estimate of the minimum amount of elevation difference needed within the BMP, from the inflow to the outflow, to allow for gravity operation.

Minimum Depth to Seasonal High Water Table: This column indicates the minimum distance that should be provided between the bottom of the stormwater management practice and the top of the water table.

Soils: This column describes the influence that the underlying soils (i.e., hydrologic soil groups) can have on the performance of the stormwater management practice.

Table 0.2 Feasibility Limitations for BMPs

BMP	Contributing Drainage Area	Slope	Minimum Head	Minimum Depth to Water Table	Soils
Bioretention	Up to 5 acres	Up to 5%[2]	2.5 -4 feet	0.5 feet	All soils[3]
Permeable Pavement	Up to 5 times practice surface area	Up to 5%	2 – 4 feet	0.5 feet	All soils[3]
Infiltration	p to 5 acres	Up to 5%[2]	2 – 4 feet	0.5 feet	Must drain within 72 hours
Green Roof	Green roof area + 25%	No limit	N/A	N/A	N/A
Rainwater Harvesting	No limit	No limit	N/A	N/A	N/A
Disconnection	Up to 1,000 ft^2 per downspout	Up to 5%	N/A	N/A	All soils
Open Channels	Up to 5 acres	Up to 5%[2]	1 – 2 feet	0.5 feet	All soils
Filtration	Up to 10 acres	Up to 5%	2 – 4 feet	0.5 feet	All soils
Dry Ponds	No limit	Up to 15%	4 – 8 feet	0.5 feet	All soils

Wet Ponds	Greater than 10 acres[1]	Up to 15%	4 – 8 feet	No limit	Slow-draining soils preferred
Stormwater Wetlands	Greater than 10 acres[1]	Up to 15%[2]	2 – 5 feet	No limit	Slow-draining soils preferred

[1]CDA can be smaller if practice intersects the water table.
[2]Check dams may be necessary to create sufficient ponding volume.
[3]Slow-draining soils may require an underdrain.

4.1 Bioretention

Bioretention					
Definition: Practices that capture and store stormwater runoff and pass it through a filter bed of engineered filter 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.					
Site Applicability		BMP Performance Summary			
Land Uses	Required Footprint	WQ Improvement: Moderate to High			
▪ Urban ▪ Suburban ▪ Rural	**Small to Large**	TSS[1]	Total N[1, 2]		Bacteria[1,3]
		80%	45-65%		55%
		Runoff Reductions			
Construction Costs	Maintenance Burden	Rate		Volume	
Moderate	Moderate	Moderate		Moderate	
Maintenance Frequency:		*SWRv*			
Routine	Non-Routine	Standard Design		Enhanced Design	
Quarterly	Every 2-3 years	60% of *Sv*		100% of *Sv*	

Advantages/Benefits	Disadvantages/Limitation
▪ Easily incorporated into new development ▪ High community acceptance ▪ Good for small, highly paved drainage areas (i.e. parking lots)	▪ Maximum CDA is 1 to 2.5 acres ▪ Requires pretreatment to prevent clogging ▪ Requires detailed landscape planning ▪ Not appropriate for steep slopes
Components	**Design considerations**
▪ Pretreatment ▪ Conveyance system ▪ Ponding area ▪ Soils/Filter Media/Mulch ▪ Observation Well/Monitoring Port ▪ Plants	▪ Maximum ponding depth 18 inches ▪ Planting bed depths between 18-36 inches ▪ Depth to seasonal high water table must be at least 6 inches ▪ Must infiltrate within 72 hours unless designed with internal water storage ▪ Underdrain system may be needed
Maintenance Activities	
▪ Mow turf cover periodically ▪ Replace mulch as needed to maintain depth of mulch	▪ Replace plant material, as needed ▪ Replace soil if it becomes clogged ▪ Clean conveyance system(s)

[1] *expected annual pollutant load removal*

[2] *In order to receive the full credit for nitrogen removal internal water storage is required.*

[3] *In order to receive the full credit for bacteria removal a minimum media depth of 24" is required.*

Bioretention areas, shallow depressional areas that are filled with an engineered soil media and are planted with trees, shrubs, and other herbaceous vegetation, are one of the most effective stormwater management practices that can be used to reduce post-construction stormwater runoff rates, volumes, and pollutant loads. They also provide a number of other benefits, including improved aesthetics, wildlife habitat, urban heat island mitigation, and improved air quality. See Figure 0.1 for an example image.

They are designed to capture and temporarily store stormwater runoff in the engineered soil media, where it is subjected to the hydrologic processes of evaporation and transpiration, before being conveyed back into the storm drain system through an underdrain or allowed to infiltrate into the surrounding soils. The engineered soil media is comprised of sand, soil, and organic matter.

Typically, bioretention systems are not designed to provide stormwater detention of larger storms (e.g., 2 - 50-year), but in some circumstances that may be possible. Bioretention practices should generally be combined with a separate facility to provide those controls.

Figure 0.1 Bioretention in Parking Lot
Photo: Center for Watershed Protection

Definition. Practices that capture and store stormwater runoff and pass it through a filter bed of engineered filter 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 the following:

B-1 Bioretention

B-2 Streetscape bioretention

B-3 Engineered tree pits

B-4 Stormwater planters

B-5 Residential rain gardens (for single family homes)

Bioretention systems are typically not designed to provide stormwater detention of larger storms (e.g., 2 - 50-year), but they may be in some circumstances. Bioretention practices shall generally be combined with a separate facility to provide those controls.

There are three different types of standard bioretention design configurations:

- **Standard Designs (with underdrain)**. Practices with a standard underdrain design and at least 18 inches of filter media depth (see Figure 0.2).
- **Standard Design (with internal water storage).** Practices with an underdrain that is piped to a sump with standpipe and bottom drain.
- **Enhanced Designs (with or without underdrain)**. Practices with underdrains that contain at least 24 inches of filter media depth and an infiltration sump/storage layer (see Figure 0.4) or practices that can infiltrate the design storm volume within 72 hours (see Figure 0.).

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.

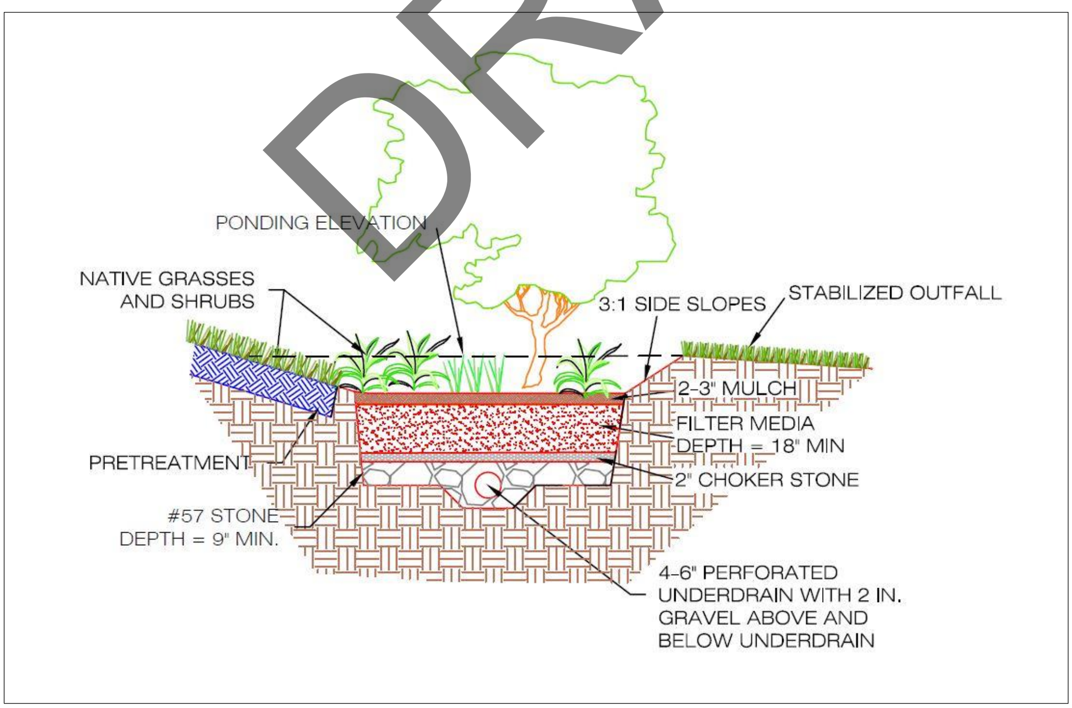

Figure 0.2 Example of standard bioretention design.

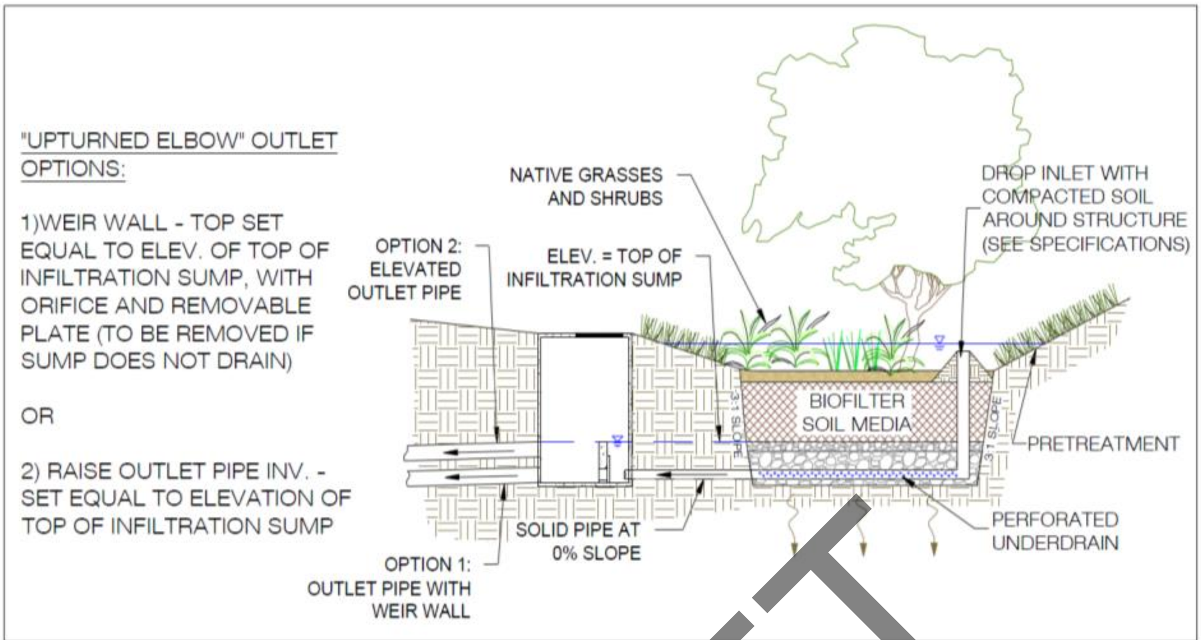

Figure 4.3 Example of standard bioretention design with infiltration sump and internal water storage

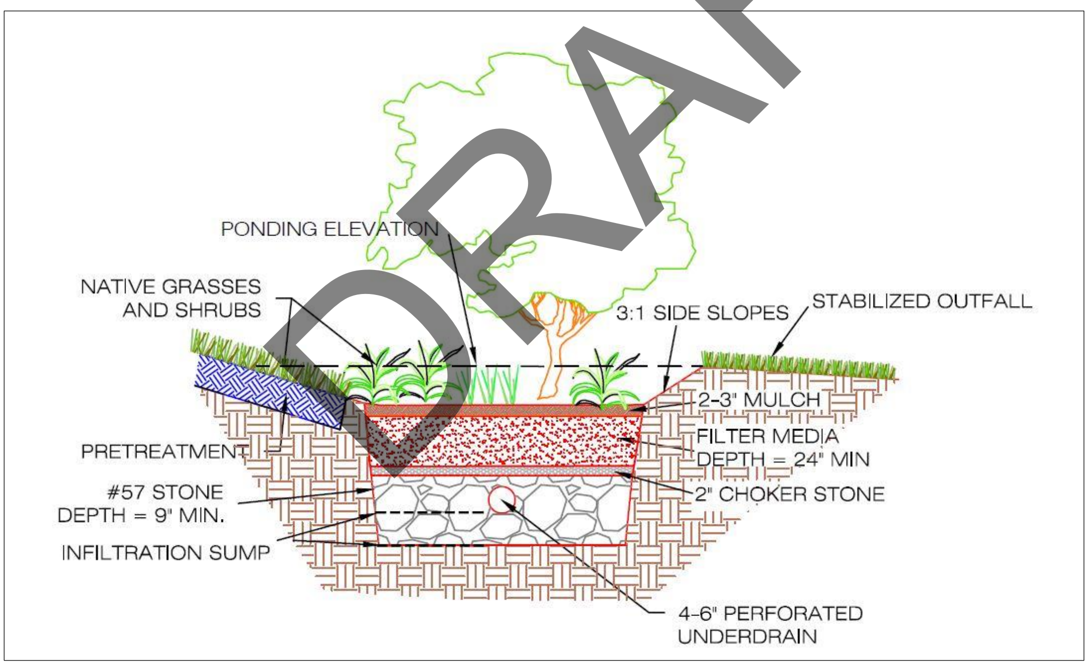

Figure 0.4 Example of an enhanced bioretention design with an underdrain and infiltration sump/storage layer

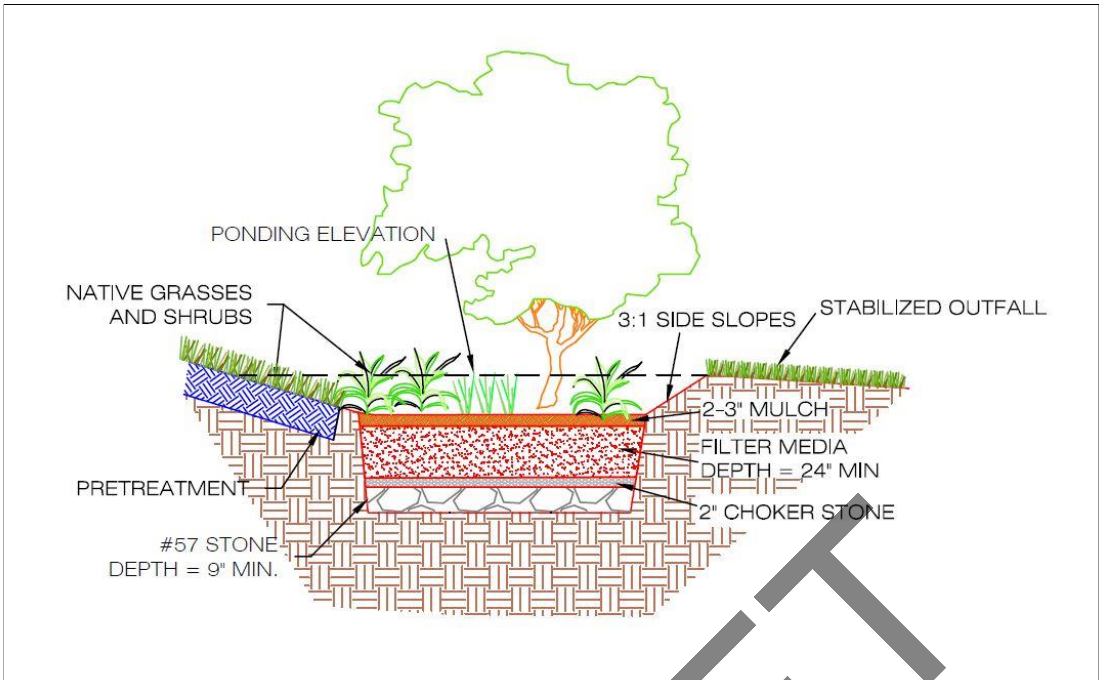

Figure 0.5 Example of enhance bioretention design without an underdrain

Figure 0.6 Example of streetscape bioretention

4.1.1 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 CDA and the corresponding bioretention surface area. The surface area is recommended to be approximately 3 to 6% of CDA, depending on the imperviousness of the CDA and the desired bioretention ponding depth.

Site Topography. Bioretention can be used for sites with a variety of topographic conditions, but is best applied when the grade of the area immediately adjacent to the bioretention practice (within approximately 15 to 20 feet) is greater than 1% and less than 5%.

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 no less than 0.5 feet is required between the bottom of the excavated bioretention area and the seasonally high groundwater table.

Tidal Impacts. For systems with an underdrain, the underdrain should be located above the tidal mean high water elevation. For entirely infiltration-based systems, the bottom of the stone reservoir should be located above the mean high water elevation. Where this is not possible, portions of the practice below the tidal mean high water elevation cannot be included in the volume calculations. Also, salt-tolerant vegetation may be necessary in these areas.

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 0.3 inches per hour. When designing a bioretention practice, designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix B for Geotechnical Information Requirements for Underground BMPs. 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 CDA to a standard bioretention area (B-1) is 2.5 acres and can consist of up to 100% impervious cover. The CDA 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 CDAs, such as off-line or low-flow diversions, or forebays, there may be case-by-case instances where the maximum CDAs can be adjusted. Table 0.3 summarizes typical recommendations for bioretention CDAs.

Table 0.3 Maximum Contributing Drainage Area to Bioretention

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

Pollutant Hotspot Land Uses. Bioretention may not be an appropriate stormwater management practice for certain pollutant-generating sites. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil- water separator or filtering device must be provided. These pretreatment facilities should be monitored and maintained frequently to avoid negative impacts to the bioretention area and subsequent water bodies.

On sites with existing contaminated soils, infiltration is not allowed. 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.

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.

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. During the establishment period of the bioretention area, irrigation is allowed, however, to ensure plant survival. In addition, rain gardens or bioretention practices may be incorporated into the design of a Rainwater Harvesting System (See Section 4.5).

Setbacks. To avoid the risk of seepage, stormwater cannot flow from the bioretention area reservoir layer to the traditional pavement base layer, existing structure foundations, or future foundations which may be built on adjacent properties.

Bioretention areas should be located at least:

- 10 feet from building foundations*
- 10 feet from property lines
- 150 feet from private water supply wells
- 50 feet from septic systems

*For building foundations, 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) to prevent seepage or foundation damage.

Proximity to Utilities. Designers should ensure that future tree canopy growth in the bioretention area will not interfere with existing overhead utility lines. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the PROW. Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the bioretention system. 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.
- 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 liner 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 owner will replace the bioretention or, alternatively, install a functionally comparable bioretention according to the specifications in the current version of this guidebook. If the bioretention is located in the PROW, the bioretention restoration will also conform with the State of South Carolina Department of Transportation design 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 *<local jurisdiction>* may also apply (e.g., State Department of Transportation).

Economic Considerations. Bioretention areas can be particularly cost effective when they are included in areas of the site already planned for landscaping.

4.1.2 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 CDA 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 should be designed off-line so that flows 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 filter 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 SWRv) to enter the facility (calculations must be made to determine the peak flow from the 85th or 95th percentile 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 (see Figure 0.7). 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 to 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 - 50-year design storms must be controlled so that velocities are non-erosive (generally less than 6 feet per second) at the outlet point, to prevent downstream erosion.

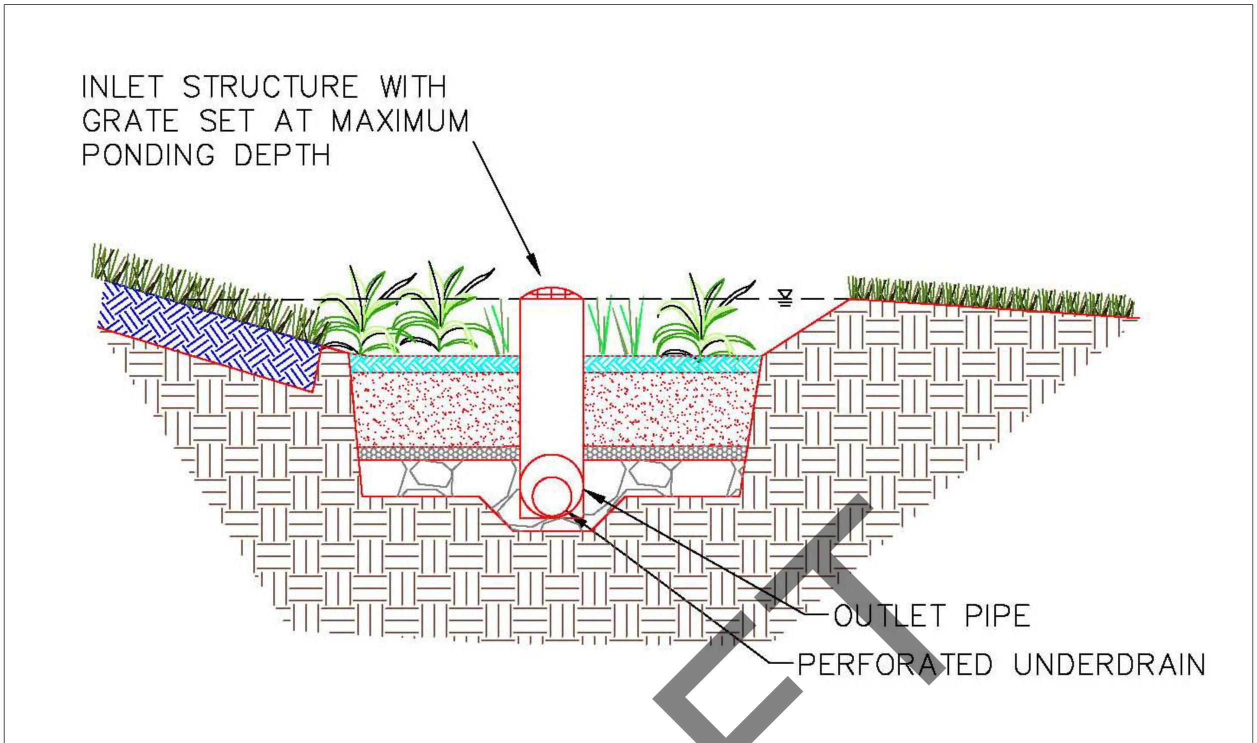

Figure 0.7 Example of an overflow structure in an on-line bioretention area

4.1.3 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:

Standard 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 dissipator sized for the expected rates of discharge. It has a storage volume equivalent to at least 15% 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 filter 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 5H:1V slope or flatter. Alternatively, if the bioretention basin has side slopes that are 3H:1V or flatter, a 5-foot grass filter strip can be used at a maximum 5% (20H:1V) 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 4.8 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 0 Proprietary Practices for information on approved proprietary structures.

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

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.

4.1.4 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. So that 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 dissipators.
- 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.

Inlets must be designed with sufficient width and slope to avoid unintended bypass. This is of particular concern for curb cuts on streetscape bioretention designs.

Ponding Depth. The recommended surface ponding depth is 6 to 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 to 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 3H:1V or flatter. In 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 of a bioretention practice consists of an engineered soil mixture that has been carefully blended to create a filter media that maintains long-term permeability while also providing enough nutrients to support plant growth. The final filter media shall consist of a well-blended mixture of medium to coarse **sand**, **loam soil**, and an **organic amendment** (compost). The sand maintains the desired permeability of the media while the limited amount of loam soil and organic amendments are considered adequate to help support initial plant growth. It is anticipated that the gradual increase of organic material through natural processes will continue to support plant growth without the need to add fertilizer, and the root structure of maturing plants and the biological activity of the media will maintain sufficient long-term permeability.

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

- **Sand (Fine Aggregate).** Sand should consist of silica-based medium to coarse sand and be angular or round in shape. The materials shall not be derived from serpentine, shall be free of surface coatings or any other deleterious materials, and shall contain less than 0.5% mica by weight when tested with ASTM C295, Standard Guide for Petrographic Examination of Aggregates for Concrete.

  ASTM C-33 concrete sand will typically meet the requirements for the sand to be used in filter media. However, some samples of ASTM C-33 sand may have too high a fraction of fine sand and silt- and clay-sized particles to meet the final filter media particle size distribution requirements. In general, coarser gradations of ASTM C-33 will better meet the filter media particle size distribution and hydraulic conductivity requirements.

Any other materials, such as manufactured sand, limestone-based sands, or crushed glass, shall meet the required particle size distribution (of final filter media mixture) and be demonstrated as adequately durable when tested by AASHTO T-103 or T-104.

- **Loam Soil.** Loam soil is generally defined as the combination of sand-sized material, 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 in the final filter media, the designer (or contractor or materials supplier) must carefully select the topsoil source material so as not exceed the amount of any one ingredient.

  Generally, a natural loamy sand, sandy loam, or loam (per the USDA Textural Triangle) A-horizon topsoil free of subsoil, large stones, earth clods, sticks, stumps, clay lumps, roots, viable noxious weed seed, plant propagules, brush, or other objectionable, extraneous matter or debris is suitable for the loam soil source material.

- **Organic Amendments.** Organic amendments shall consist of stable, well-composted, natural, carbon-containing organic materials such as leaf mulch, peat moss, humus, or yard waste (consistent with the material specifications found in Appendix C Soil Compost Amendment Requirements). The material shall be free of debris such as plastics, metal, concrete, stones larger than ½ inch, larger branches and roots, and wood chips over 1 inch in length or diameter.

Complete Filter Media. The complete filter media shall consist of a pug milled or mechanically blended mix of the three source materials. Mixing the filter media on site with excavation or loading equipment is not sufficient to achieve the required blending. The resulting filter media must meet the following particle size composition:

- 80%–90% sand
- 10%–20% silt and clay
- Maximum 10% 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.

Note: The above percentages are based on weight rather than volume.

Additionally, the final filter media mix must either meet the grain size distribution indicated in **Table 0.4**, or have a saturated hydraulic conductivity of 2 to 6 inches per hour according to test procedure ASTM D2434 when compacted (at 60% to 80% optimum moisture content) to a minimum of 86% of the maximum density as determined by AASHTO T 99 (ASTM, 2006).

Table 0.4 Filter Media Grain Size Distribution

Sieve Type	Particle Size (mm)	Percent Passing (%)
-	8.0	100
No. 5	4.0	92–100
No. 10	2.0	72–100

No. 18	1.0	43–95
No. 35	0.5	20–65
No. 60	0.25	11–37
No. 140	0.105	10–25
No. 270	0.053	10–20
-	0.002	0–10

The filter media shall also meet the following criteria (see summary in **Table 0.5**):

- Organic content shall be between 3.0% and 5.0% by weight;
- pH shall be between 6.0 and 7.5;
- Cation exchange capacity (CEC) shall be a minimum of 5 meq/100g or cmol+/kg;
- Phosphorus content shall meet one of the following:
  - P-Index between 10 and 30;
  - 5 to 15 mg/kg Mehlich I Extraction;
  - 18 to 40 mg/kg Mehlich III Extraction; and
- Soluble salts shall be less than 500 ppm or less than 0.5 mmhos/cm.

Notes:

1. P-Index is an agronomic test used in North Carolina to indicate the potential for P leaching from soil. The test method has been revised to add P concentration to facilitate local lab testing. The value of the P-Index is the correlation between the CEC and P concentrations: higher CEC indicates greater adsorption sites within the media, thus increasing the ability to fix P within the soil, thereby allowing higher P concentrations without leaching. While P-Index may be a better overall representation of P, the test method may not be readily available.
2. Tests for organic content, CEC, soluble salts, and pH are referenced to be in accordance with Recommended Soil Testing Procedures from the Southeastern United States, Current Edition, Southern Cooperative Series Bulletin No. 419. Use the following tests from **Southern Cooperative Series Bulletin No. 419:**

   (a) Test for soil content by loss of weight on ignition

   (b) Test for soil CEC by exchangeable acidity method

   (c) Test for soluble salts shall be by the 1:2 (v:v) soil:water Extract Method

   (d) Test for pH by the SMP method

Table 0.5 Summary of Filter Media Criteria for Bioretention

Filter Media Criterion	Description	Standard(s)
General Composition	Filter media must have the proper proportions of sand, loam soil, and organic amendments to promote plant growth, drain at the	80%–90% sand; 10%–20% soil fines; maximum of 10% clay; and 3%–5% organic content

Filter Media Criterion	Description	Standard(s)
	proper rate, and filter pollutants.	Must meet final filter media grain size distribution OR have a saturated hydraulic conductivity of 2–6 inches per hour
Sand	Medium to coarse aggregate	Based on final filter media grain size distribution
Loam Soil	Loamy sand, sandy loam, or loam	USDA Textural Triangle
Organic Amendments	Stable, well-composted, natural, carbon-containing organic materials such as leaf mulch, peat moss, humus, or yard waste.	Appendix C
P-Index or Phosphorus (P) Content	Filter media with high P levels will export P through the media and potentially to downstream conveyances or receiving waters.	P-Index of 10–30 or P content = 5–15 mg/kg (Mehlich I) or 18–40 mg/kg (Mehlich III)
Cation Exchange Capacity (CEC)	The CEC is determined by the amount of soil fines and organic matter. Higher CEC will promote pollutant removal.	CEC > 5 milliequivalents per 100 grams
pH	Soil pH influences nutrient availability and microbial populations.	Between 6.0 and 7.5
Soluble Salts	Filter media with high levels of soluble salts can injure or kill plants.	Less than 500 ppm or less than 0.5 mmhos/cm.

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 *<local jurisdiction>*.

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. **In order to receive the full credit for bacteria removal a minimum media depth of 24” is required.** The media depth must not exceed 6.5 feet. Turf, perennials, or shrubs should be used instead of trees to landscape shallower filter beds. See Table 0.8 and Table 0.9 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 filter media. This is dependent upon the surface area of the BMP (SA) relative to the 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 0.6). 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 Rv_{CDA} is an average of runoff coefficients of land cover types in the BMP's CDA. The land cover runoff coefficient types can be selected from Table I.1 Runoff Coefficient Factors for Rational Method or using the three categories established for calculating the SWRv (natural, compacted, and impervious cover). The applicable filter media depth from Table 0.6 should be used as d_{media} in Equation 0.5. Note: In the gray cells, overflow is not likely to occur for the design storm, so no maximum filter media depth is specified.

Table 0.6 Determining Maximum Filter Media Depth (feet)

*S*A:CDA (%)	***Rv***								
	0.25	**0.3**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**0.95**
0.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
1.0	5.0	5.5	6.0	6.5	6.5	6.5	6.5	6.5	6.5
1.5	3.5	4.0	5.0	6.0	6.0	6.5	6.5	6.5	6.50
2.0		3.0	4.0	4.5	5.5	6.0	6.0	6.5	6.5
2.5			3.5	4.0	4.5	5.0	5.5	6.0	6.0
3.0				3.5	4.0	4.5	5.0	5.5	5.5
3.5					3.5	4.0	4.5	5.0	5.0
4.0					3.0	3.5	4.0	4.5	4.5
4.5						3.5	3.5	4.0	4.0
5.0							3.5	4.0	4.0
5.5								3.5	3.5
6.0								3.0	3.5
6.5									3.0
7.0+									

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, is recommended/required for surface cover, as it retains a significant amount of pollutants and typically will not float away. The maximum depth of the mulch layer is 3 inches.
- **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 C Soil Compost Amendment Requirements, 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 filter 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 (10 times) higher 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 4.1.1 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 three or four rows of 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 maximum depth of the underdrain stone layer combined with the choking layer is 12 inches, and it cannot extend beyond the surface dimensions of the bioretention filter media. The underdrain must be sized so that the bioretention BMP fully drains within 72 hours or less.

Multiple underdrains may be necessary for bioretention areas wider than 40 feet, and each underdrain is recommended to 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. Each underdrain must include a cleanout pipe (minimum 4 inches in diameter).

All bioretention practices should 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.

Upturned Elbow (optional). In cases where limited head is a site constraint and the bioretention must be designed to be relatively shallow (e.g., depth to groundwater, relatively flat sites, or other factors), or where increased nitrogen removal is desired, an upturned elbow underdrain design can be used. **In order to receive the full credit for nitrogen removal internal water storage is required.** For more information on this design consult North Carolina Stormwater Design Manual Chapter C-2. (NCDEQ, 2017)

Observation Wells. All bioretention practices must include at least one observation well consisting of a well-anchored, 4- to 6-inch diameter PVC pipe (see Figure 0.8). For standard bioretention practices, the non-perforated observation wells should be tied into any of the Ts or Ys in the underdrain system and must extend upward above the ponding level. These observation wells can also double as cleanouts. Enhanced bioretention practices should be perforated in the gravel layer only and also must extend upward to the top of ponding.

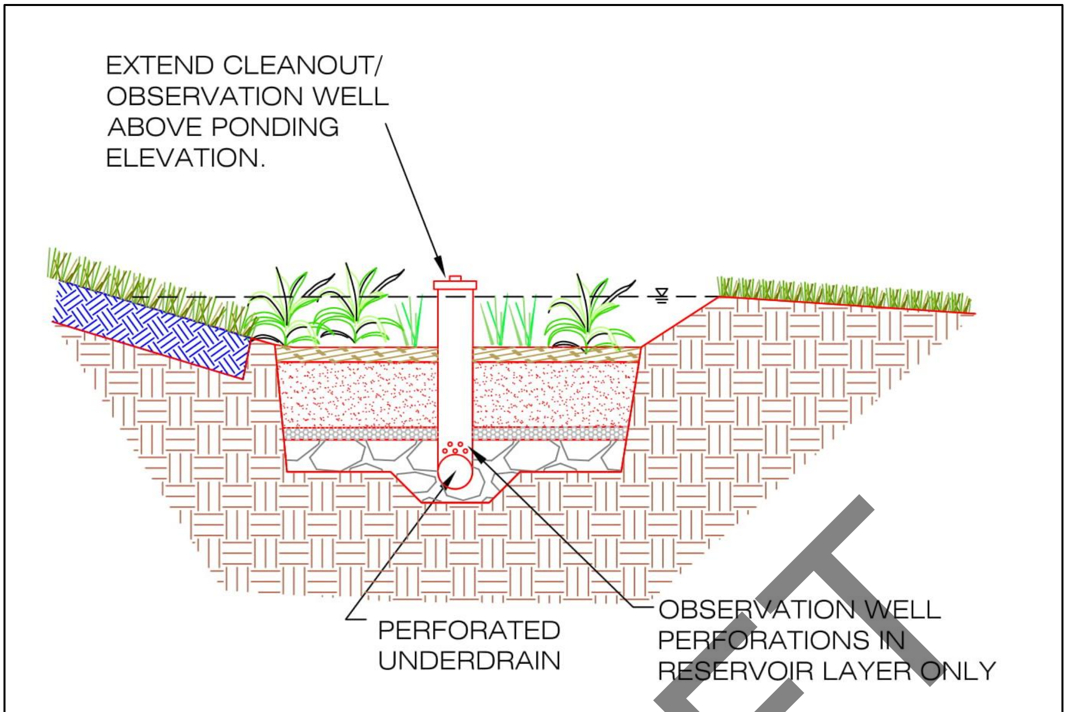

Figure 0.8 Observation well/cleanout device.

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. Unlike the underdrain stone layer, this storage layer can be extended beyond the surface dimensions of the bioretention filter media if additional storage volume is needed. To qualify for the Enhanced Design, this underground storage layer must be designed to infiltrate within 72 hours. The underground storage layer may also be designed to provide detention for the 2 - 50-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. Suitable conveyance must also be provided to ensure that the storage is fully utilized without overflow of the bioretention area.

Impermeable Liner (optional). 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 PVC geomembrane liner or equivalent of an appropriate thickness (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 0.7.

Table 0.7 Bioretention Material Specifications

Material	Specification	Notes
Filter Media	▪ See Table 0.5 and Table 0.6	Minimum depth of 24 inches (18 inches for standard design). 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 (10 times) higher 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 PVC Geomembrane liner or equivalent material of an appropriate thickness.	
Underdrains, Cleanouts, and Observation Wells	Use 4- or 6-inch rigid schedule 40 PVC pipe, or equivalent corrugated HDPE for small bioretention BMPs, with three or four rows of 3/8-inch perforations at 6 inches on center. Multiple underdrains may be necessary for bioretention areas wider than 40 feet, and each underdrain is recommended to 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 of ponding.
Plant Materials	See Section 4.1.5 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 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. Streetscape bioretention in the PROW should comply with State Department of Transportation requirements, where applicable.

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 (see Figure 0.9). 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. Engineered tree boxes in the PROW should comply with State Department of Transportation requirements, where applicable.

When designing engineered tree boxes, the following criteria may apply.

- Engineered tree box designs sometimes cover portions of the filter media with pervious pavers or cantilevered sidewalks (see Figure 0.10). In these situations, the following design considerations must be incorporated:
    - The filter media must be connected beneath the surface so that stormwater and tree roots can share this space.
    - As with all bioretention areas, a minimum surface ponding depth of 3 inches, averaged over the surface area of the bioretention area, is required. For example, if the additional surface area under the pavement doubles the overall surface area, then the ponding depth will need to be at least 6 inches.
    - Sand based structural soil (SBSS) may be considered as bioretention filter media if it meets the same phosphorus content limits. However, if the SBSS is to be compacted beyond the State Standards' maximum compaction for bioretention, it shall be assigned a porosity of 0.10. The State Standards call for bioretention soil to be compacted to 84% maximum dry density while SBSS is to be compacted to 93%.
- 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 4.12 Tree Planting and Preservation.
- See Section 4.12.2 Planting Trees and Figure 0.57 for further guidance and requirements on tree planting.

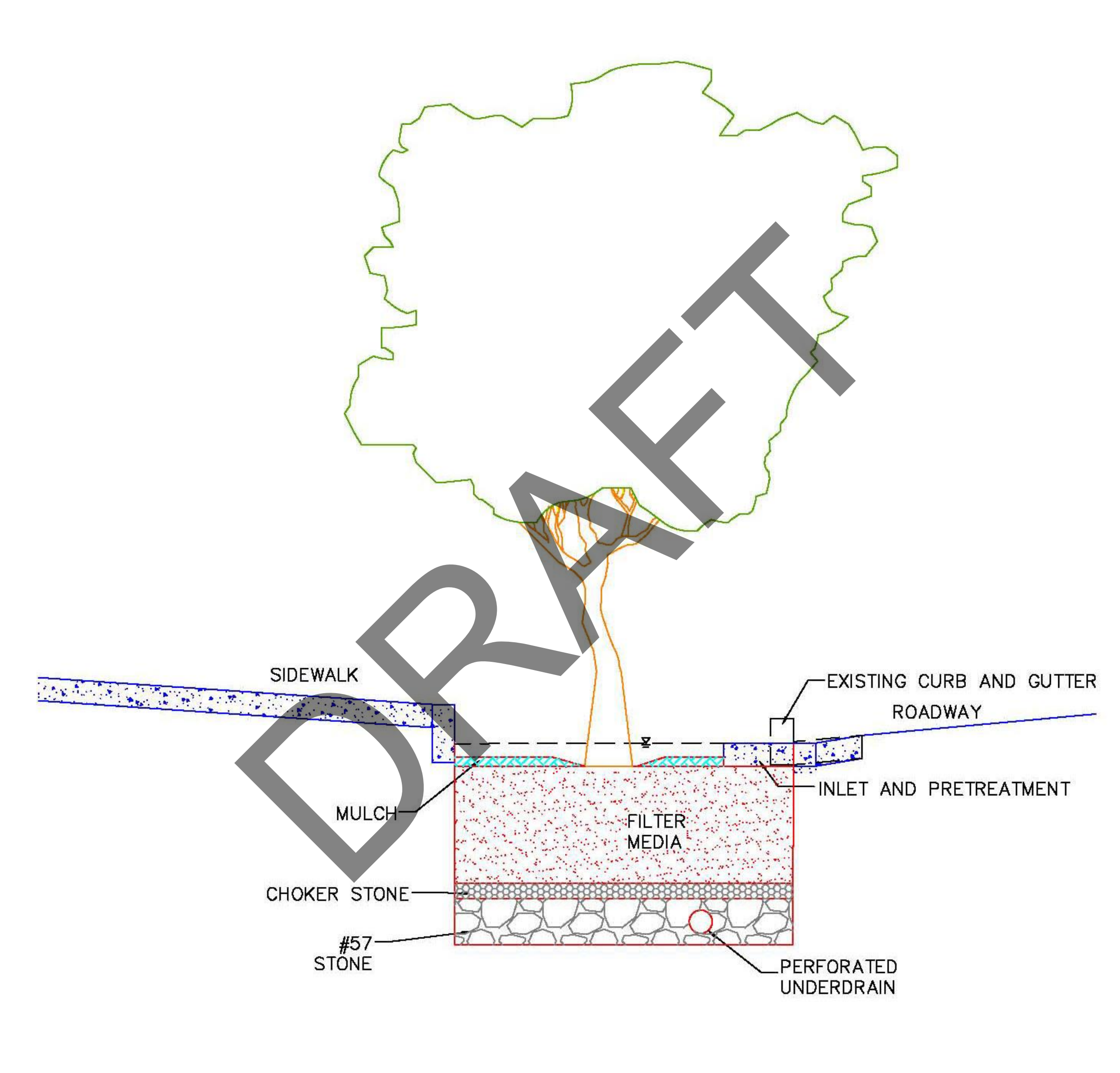

Figure 0.9 Example of tree box cross section.

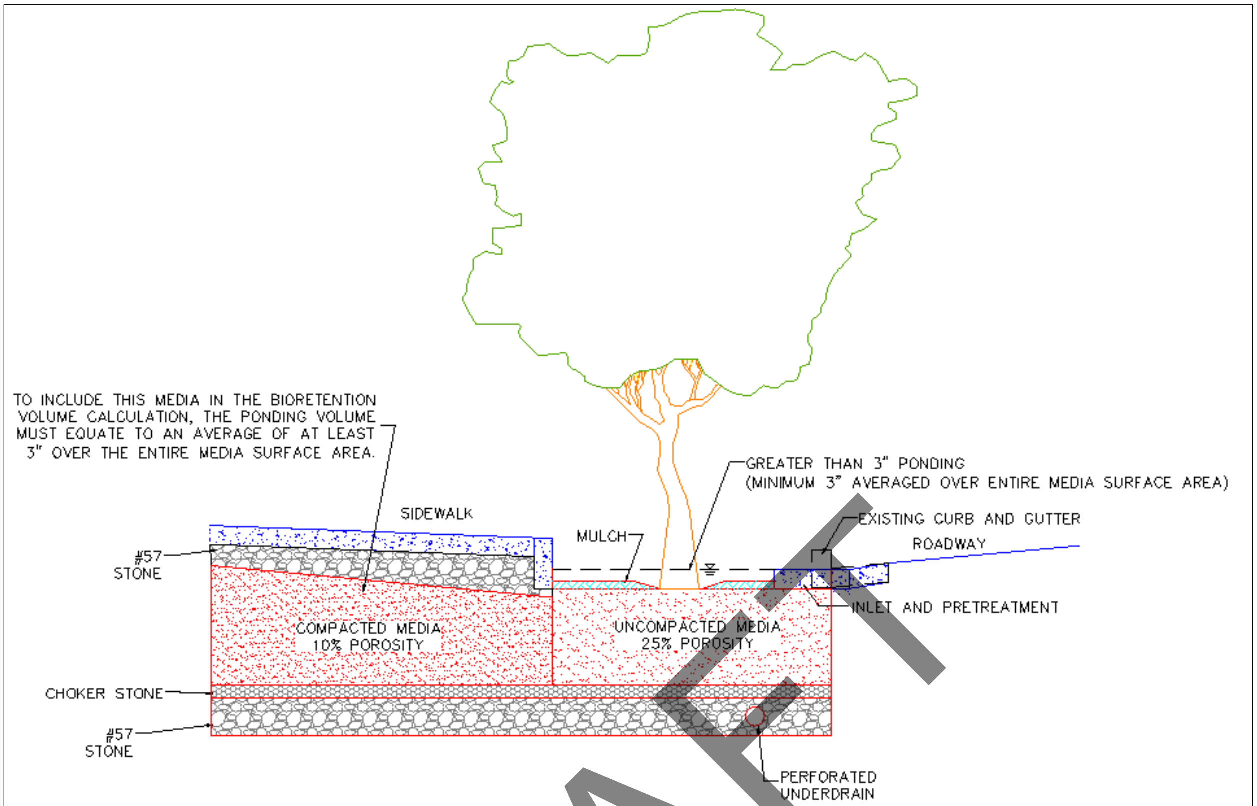

Figure 0.10 Example of tree box cross section with compacted media extending below sidewalk.

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 tolerate 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 0.11.

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.

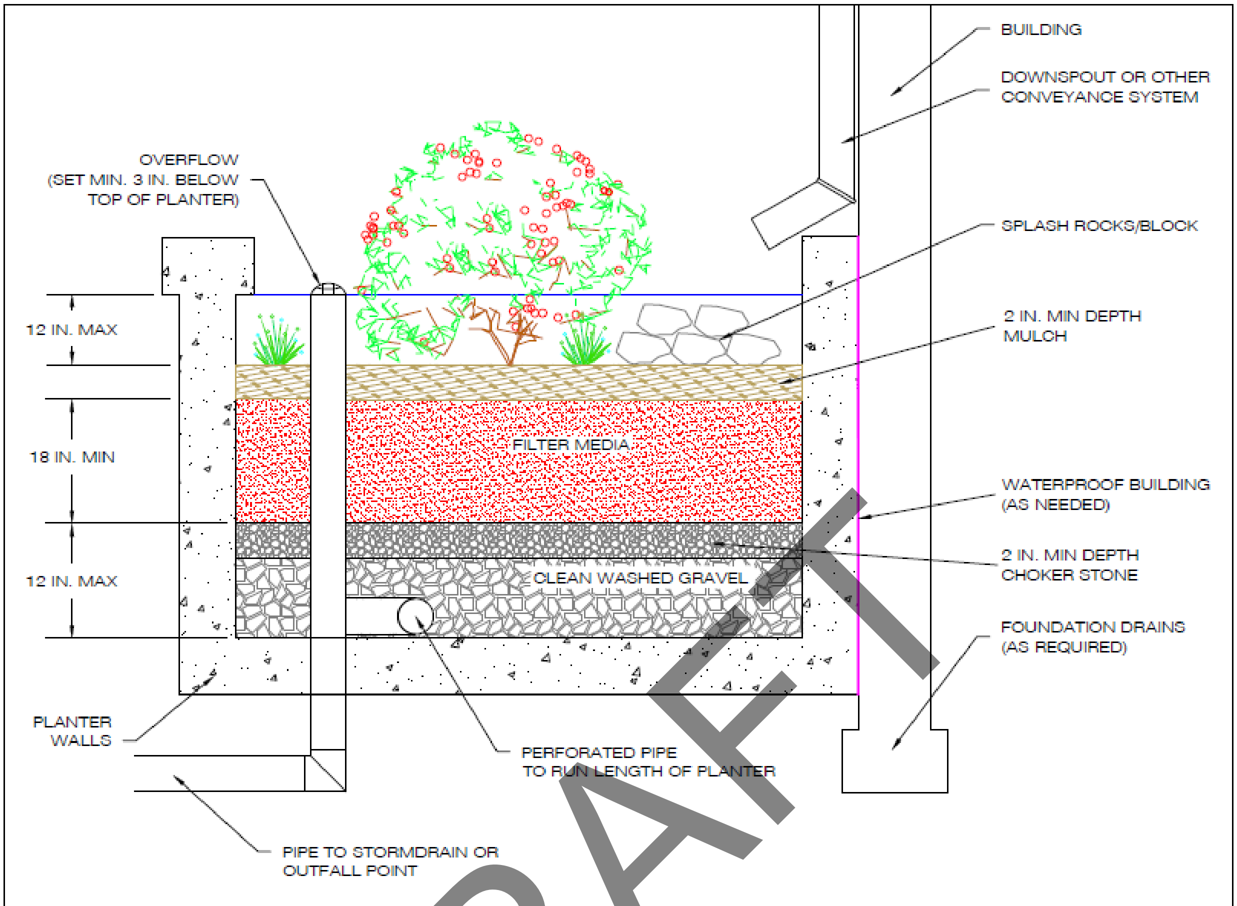

Figure 0.11 Example of a stormwater planter (B-4).

All planters should be placed at grade level or above ground. Plant materials must be capable of withstanding moist and seasonally dry conditions. The 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, filter media, and gravel reservoir layers of the BMP.

Total storage volume of the BMP is calculated using Equation 0.1.

Equation 0.1 Bioretention Storage Volume

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

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, including mulch layer (ft)
η_{media}	=	effective porosity of the filter media (typically 0.25)
d_{gravel}	=	depth of the underdrain and underground storage gravel layer, including choker stone (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 0.1 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 4.9 Storage Practices.

For enhanced bioretention areas, the volume that will be infiltrated (the sump volume for underdrained designs or the entire volume for non-underdrained designs) must infiltrate within 72 hours. The saturated hydraulic conductivity for the native soils must exceed 0.05 feet per day to qualify for the enhanced design retention value. The depth of the infiltration sump for underdrained designs can be determined using Equation 0.2.

Equation 0.2 Bioretention Infiltration Sump Depth

$$d_{sump} = \frac{(K_{sat} \times t_d)}{\eta_r}$$

where:

d_{sump}	=	depth of the infiltration sump (in.)
K_{sat}	=	field-verified saturated hydraulic conductivity for the native soils (ft/day) (must exceed 0.1 ft/day)

t_d	=	drawdown time (3 days)
n_r	=	available porosity of the stone reservoir (assume 0.4)

For non-underdrained designs, a check must be performed to ensure that the entire Sv infiltrates within 72 hours, as in Equation 0.3.

Equation 0.3 Bioretention Infiltration Rate Check

$$Sv_{infiltrate} = \frac{SA_{bottom}(K_{sat} \times t_d)}{12}$$

where:

$Sv_{infiltrate}$	=	storage volume that will infiltrate within 72 hours (ft^3)
SA_{bottom}	=	bottom surface area of bioretention (ft^2)
K_{sat}	=	field-verified saturated hydraulic conductivity for the native soils (ft/day)
t_d	=	drawdown time (3 days)

If $Sv_{infiltrate}$ is greater than or equal to Sv, then the entire Sv will infiltrate within 72 hours. If it is not, the storage volume of the bioretention area should be reduced accordingly.

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 - 50-year runoff volumes to satisfy stormwater quantity control requirements. At least 3 to 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 - 50-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}).

4.1.5 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) 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 0.8 through Table 0.10.

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 that 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 0.8 Bioretention-Appropriate Plants: Perennial and Grass

Scientific Name	Common Name	Wetland Indicator [1]	Inundation Tolerance	Salt Tolerance	Notes
Aletris farinosa	White Colicroot	FAC	Moist soil	None	
Andropogon gerardii	Big Bluestem	FAC	No	Moderate	
Aquilegia canadensis	Wild Columbine	FACU	No	None	
Asclepias incarnata	Swamp Milkweed	OBL	Saturated	None	
Asclepias lanceolata	Red Milkweed	OBL	Wet soils	Moderate / brackish	
Aster novae-angliae	New England Aster	FACW	Moist soils, yes	Yes	
Athyrium filix-femina	Lady Fern	FAC	Moist to wet soils	None	
Canna glauca	Water Canna	OBL	Moist to wet soils	None	
Canna flaccida	Golden Canna	OBL	Moist to wet soils	None	
Carex stricta	Tussock Sedge	OBL	Saturated, 0-6"	None	
Chasmanthium latifolium	River Oats	FAC	Moist soils	None	

Scientific Name	Common Name	Wetland Indicator [1]	Inundation Tolerance	Salt Tolerance	Notes
Chelone glabra	White Turtlehead	OBL	Moist to wet soils		
Conoclinium coelestinum	Blue Mistflower	FAC	Moist to Wet soils		
Crinum americanum	Southern Swamp Lily	OBL	Saturated		
Dulichium arundinaceum	Threeway Sedge	OBL	Saturated, shallow	None	
Echinodorus cordifolius	Creeping Burhead	OBL	Saturated, shallow		
Equisetum hyemale	Scouring Rush	FACW	Saturated, shallow		
Eupatorium fistulosum	Joe Pye Weed	FACW	Moist to Wet Soils		
Geranium maculatum	Spotted Geranium	FACU	Moist Soils		
Helianthus angustifolius	Swamp Sunflower, Narrowleaf Sunflower	FACW	Wet Soils		
Hibiscus coccineus	Scarlet Swamp Hibiscus	OBL	Saturated, shallow		
Hibiscus moscheutos	Rose Mallow, Hibiscus	OBL	Saturated, shallow	Low	
Hymenocallis caroliniana	Spider Lily	OBL	Saturated, shallow	None	
Iris versicolor	Virginia Iris	OBL	Shallow	None	
Juncus effuses	Common Rush	OBL	Shallow <6”	Low	
Liatris spicata	Gayfeather, Blazing Star	FAC	Moist Soils	Low	
Lobelia cardinalis	Cardinal Flower	FACW	Moist to Wet Soils	None	
Lobelia siphilitica	Blue Lobelia	OBL	Moist to wet soils		
Lysimachia ciliata	Fringed Loosestrife	FACW	Moist to wet soils, seasonal flooding		
Mimulus ringens	Allegheny Monkeyflower	OBL	Saturated, shallow		
Onoclea sensibilis	Sensitive Fern	FACW	Moist to wet soils		

Scientific Name	Common Name	Wetland Indicator [1]	Inundation Tolerance	Salt Tolerance	Notes
Osmunda cinnamomea	Cinnamon Fern	FACW	Moist to wet soils	Low	
Osmunda spectabilis	Royal Fern	OBL	Moist to wet soils	None	
Orontium aquaticum	Golden Club	OBL	Up to 10”		
Panicum virgatum	Switch Grass	FAC	Moist soil	Moderate	
Peltandra virginica	Green Arrow Arum	OBL	Shallow < 1’	Low (< 2 ppt)	
Pontederia cordata	Pickerelweed	OBL	Shallow < 1’	Low (< 3 ppt)	
Physostegia virginiana	Obedient Plant	FACW	Moist soil		
Polygonatum biflorum	Great Solomon’s Seal	FACU	Moist soil		
Rhynchospora colorata	Starrush Whitetop	FACW	Saturated		
Rudbeckia laciniata	Cutleaf Coneflower	FACW	Moist soil	None	
Sagittaria latifolia	Common Arrowhead, Duck Potato	OBL	Up to 2.0’	None	
Saururus cernuus	Lizard’s Tail	OBL	Shallow < 4”	None	
Schizachyrium scoparium	Little Bluestem	FACU	Moist soil	None	
Schoenoplectus tabernaemontani	Softstem Bulrush	OBL	Wet soil to standing water	Fresh or Brackish	
Solidago sempervirens	Seaside Goldenrod	FACW	Yes	High	
Sorghastrum nutans	Indiangrass	FACU	Moist soil	Moderate	
Spartina alterniflora	Saltmarsh Cordgrass	OBL	Yes	High	
Spartina bakeri	Sand cordgrass	FACW	Moist to wet soils	Fresh - Saline	
Spartina patens	Saltmeadow Cordgrass	FACW	Wet soils	High	
Thalia dealbata	Powdery Alligator-flag	OBL	up to 1.5’	Yes	
Tradescantia virginiana	Virginia Spiderwort	FAC	Moist soils	None	

Scientific Name	Common Name	Wetland Indicator 1	Inundation Tolerance	Salt Tolerance	Notes
Vernonia noveboracensis	Ironweed	FACW	Moist soils	None	

1. Wetland Indicator 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

Table 0.9 Bioretention-Appropriate Plants: Shrubs and Bushes

Scientific Name	Common Name	Wetland Indicator 1	Inundation Tolerance	Salt Tolerance	Notes
Baccharis halimifolia	Groundsel Tree, Salt Myrtle	FAC	Wet soils	High	
Callicarpa americana	Beautyberry	FACU	Moist soils	None	
Cephalanthus occidentalis	Button Bush	OBL	Up to 3 ft	Low	
Clethra alnifolia	Summersweet Sweet Pepperbush	FACW	Moist to wet soils	None	
Cyrilla racemiflora	Swamp Titi	FACW	Moist to wet soils	Low	
Hamamelis virginiana	Witch Hazel	FACU	Moist to wet soils	None	
Hypericum prolificum	Shrubby St. John's Wort	FAC	Moist soils, flood tolerant	None	
Ilex glabra	Inkberry	FACW	Wet soils, flood tolerant	Moderate	
Ilex verticillata	Winterberry Holly	FACW	Moist to wet soils	None	
Ilex vomitoria	Yaupon Holly	FAC	Moist soils	Moderate	
Itea virginica	Virginia Sweetspire	FACW	Moist to wet soils	None	
Kosteletzkya virginica	Seashore Mallow	OBL	Moist to wet soils	Moderate	
Lindera benzoin	Spicebush	FACW	Seasonal inundation	None	
Myrica cerifera	Wax Myrtle	FAC	Moist to wet soils	Moderate	

Scientific Name	Common Name	Wetland Indicator [1]	Inundation Tolerance	Salt Tolerance	Notes
Photinia pyrifolia	Red Chokeberry	FACW	Moist soils	Low	
Rhododendron canescens	Dwarf Azalea	FACW	Moist soils	None	
Rhododendron viscosum	Swamp Azalea	OBL	Wet soil	None	
Rosa carolina	Carolina Rose	FACU	Moist to wet soils	Moderate	
Sabal minor	Dwarf Palmetto	FACW	Moist to wet soils	None	
Sambucus canadensis	Elderberry	FACW	Moist to wet soils	None	
Serenoa repens	Saw Palmetto	FACU	Occasionally wet	None	
Vaccinium corymbosum	Highbush Blueberry	FACW	Wet soil	High	
Viburnum dentatum	Arrowwood	FAC	Moist to wet	None	

1. Wetland Indicator 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.

Table 0.10 Bioretention-Appropriate Plants: Trees

Scientific Name	Common Name	Wetland Indicator[1]	Inundation Tolerance	Salt Tolerance	Notes
Acer rubrum	Red Maple	FAC	Seasonal inundation	None	
Amelanchier canadensis	Serviceberry	FAC	Moist to wet soils	Moderate	
Betula nigra	River Birch	FACW	Moist soils	None	
Carpinus caroliniana	American Horn-beam	FAC	Periodic flooding	None	
Celtis occidentalis	Hackberry	FACU	Moist soils	Low	
Chamaecyparis thyoides	Atlantic White Cedar	OBL	Wet soils	None	
Chionanthus virginicus	Fringetree	FACU	Moist soils	None	

Scientific Name	Common Name	Wetland Indicator[1]	Inundation Tolerance	Salt Tolerance	Notes
Cornus florida	Flowering Dog-wood	FACU	Moist soils	None	
Crataegus aestivalis	Mayhaw, May Hawthorn	OBL	Wet soils	None	
Diospyros virginiana	Persimmon	FAC	Variable moisture	Low	
Gordonia lasianthus	Loblolly Bay	FACW	Moist soils	None	
Ilex cassine	Dahoon Holly	FACW	Moist soils	Low	
Ilex opaca	American Holly	FAC	Wet soils	Moderate	
Juniperus virginiana	Eastern Red Cedar	FACU	Moist soils	Low	
Liquidambar styraciflua	Sweetgum	FAC	Moist soils	None	
Liriodendron tulipifera	Tulip Tree	FAC	Moist soils	Low	
Magnolia virginiana	Sweetbay, Magnolia	FACW	Moist soils	None	
Nyssa aquatica	Water Tupelo	OBL	Wet soils	None	
Nyssa biflora	Ogeechee Tupelo	OBL	Moist to wet soils	None	
Nyssa sylvatica	Black Gum, Black Tupelo	FAC	Moist soils; seasonal flooding	Moderate	
Ostrya virginiana	Hop Hornbeam, Ironwood	FACU	Moist soils	None	
Platanus occidentalis	American Sycamore	FACW	Saturated soils; seasonal flooding	None	
Quercus bicolor	Swamp White, Oak	FACW	Moist to wet soils	None	
Quercus lyrata	Overcup Oak	OBL	Yes	None	
Quercus michauxii	Swamp Chestnut, Oak	FACW	Moist soils	None	
Quercus nuttallii	Nuttall Oak	FACW	Extended flooding	None	
Quercus pagoda	Cherrybark Oak	FACW		None	
Quercus palustris	Pin Oak	FACW	Moist to wet soils	Low	
Quercus phellos	Willow Oak	FACW	Moist soils	None	

Scientific Name	Common Name	Wetland Indicator[1]	Inundation Tolerance	Salt Tolerance	Notes
Quercus shumardii	Shumard Oak	FAC	Short-term flooding	None	
Sassafras albidum	Sassafrass	FACU	Moist soils	None	
Taxodium ascendens	Pond Cypress	OBL	Moist soils	High	
Taxodium distichum	Bald Cypress	OBL	Wet soils; standing water	High	
Ulmus americana	American Elm	FAC	Moist soils	Low	

1. Wetland Indicator 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

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., 5 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 filter 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.

4.1.6 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 limits 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 remedies 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 bioretention 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 bioretention area can be installed.
  - Finally, if it is infeasible to keep the proposed bioretention areas outside of the limits of disturbance, 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. These steps may be modified to reflect different bioretention applications or expected site conditions:

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

Step 2: **Preconstruction Meeting.** The designer, the installer, and *<local jurisdiction>* inspector must have a preconstruction meeting, checking the boundaries of the CDA and the actual inlet elevations to ensure they conform to original design. Since other contractors may be responsible for constructing portions of the site, it is quite common to find subtle differences in site grading, drainage and paving elevations that can produce hydraulically important differences for the proposed bioretention area. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the inspector. Material certifications for aggregate, filter 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- to 15-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 at least 2 inches above the underdrain pipe, and add the choking layer or appropriate geotextile layer as a filter between the underdrain and the filter media layer. If no stone storage layer is used, start with at least 2 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 filter media must be submitted to the *<local jurisdiction>* 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 CDA 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 CDA 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 *<local jurisdiction>* 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.

Construction phase inspection checklist can be found in Appendix E Construction Inspection Checklists.

4.1.7 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 0.11.

Table 0.11 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 0.5 inch of rainfall. Conduct any needed repairs or stabilization. ▪ Inspectors should look for bare or eroding areas in the CDA 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 through 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

Frequency	Maintenance Tasks
	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 CDA 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 that 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 filter 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.

Maintenance inspection checklists for bioretention areas and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

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 the *<local jurisdiction>* 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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.

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 local, state, and federal law.

4.1.8 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% retention value for storage volume (Sv) provided by the practice (Table 0.12), and, therefore, are not considered an accepted total suspended solids (TSS) treatment practice.

Table 0.12 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% retention value and are an accepted TSS removal practice for the storage volume (Sv) provided by the practice (Table 0.13).

Table 0.13 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 4.1.4 Bioretention Design Criteria.

Note: Additional retention value can be achieved if trees are utilized as part of a bioretention area (see Section 4.12 Tree Planting and Preservation).

Bioretention also contributes to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the storage volume (Sv) from the total runoff volume for the 2-year through the 100-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN 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.

4.1.9 References

ASTM C295 / C295M-12, Standard Guide for Petrographic Examination of Aggregates for Concrete, ASTM International, West Conshohocken, PA, 2012, www.astm.org

ASTM D2434-68(2006), Standard Test Method for Permeability of Granular Soils (Constant Head) (Withdrawn 2015), ASTM International, West Conshohocken, PA, 2006, www.astm.org

ASTM D448-12(2017), Standard Classification for Sizes of Aggregate for Road and Bridge Construction, ASTM International, West Conshohocken, PA, 2017, www.astm.org

Bioretention Manual, Prince George's Town Programs and Planning Division-Department of Environmental Resources, 2001. http://www.co.pg.md.us/Government/AgencyIndex/DER/ESD/Bioretention/bioretention.asp?nivel=foldmenu(7)

North Carolina Department of Environmental Quality. Stormwater Design Manual. Available at https://deq.nc.gov/sw-bmp-manual

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.

Carolina Clear. 2009. Rain Gardens: A Rain Garden Manual for South Carolina. Clemson University: Clemson, SC. Available online at http://www.clemson.edu/psapublishing/_pages/HORT/IL87.PDF

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

Halfacre-Hitchcock, Angela and Daniel Hitchcock. 2005. Critical line buffer ordinances: Guidance for coastal communities. College of Charleston and SC Sea Grant Extension Program. Charleston, SC. Available online at https://www.scdhec.gov/HomeAndEnvironment/_Docs/CLBO_Manual.pdf

Georgia Storm Water Management Manual Sediment, Atlanta Regional Commission and Georgia Department of Natural Resources-Environmental Protection Division, 2001. http://www.georgiastormwater.com/

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

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

Lady Bird Johnson Wildflower Center. 2013. Native Plant Database. The University of Texas at Austin, Austin, TX 78739 USA. http://www.wildflower.org/plants/

Manual of Stormwater Best Management Practices, North Carolina Department of Environment and Natural Resources-Division of Water Quality, 2005. http://h2o.enr.state.nc.us/su/bmp_updates.htm

Maryland Department of the Environment. 2001. Maryland Stormwater Design Manual. http://mde.maryland.gov/programs/Water/StormwaterManagementProgram/Pages/stormwater_design.aspx

Pervious Concrete Pavements, Paul D. Tennis, Michael L. Leming, and David J. Akers, 2004. http://www.concrete.org/pubs/newpubs/pcp.htm

Polomski, B., D. Shaughnnesy and J. Williamson. 2004. “Planting Trees Correctly.” Pre- pared for: Clemson University Cooperative Extension. http://www.clemson.edu/extension/hgic/plants/landscape/trees/hgic1001.html

Prince George’s Co., MD. 2007. Bioretention Manual. http://www.aacounty.org/DPW/Highways/Resources/Raingarden/RG_Bioretention_PG%20CO.pdf

Recommended Soil Testing Procedures from the Southeastern United States. Southern Cooperative Series Bulletin 419, Southern Extension and Research Activity Information Exchange Group - 6 http://aesl.ces.uga.edu/sera6/PUB/MethodsManualFinalSERA6.pdf .

Saxton, K.E., W.J. Rawls, J.S. Romberger, and R.I. Papendick. 1986. “Estimating generalized soil-water characteristics from texture.” Soil Sci. Soc. Am. J. 50(4):1031-1036.Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. http://chesapeakestormwater.net/

Smith, R.A. and Hunt, W.F. III. 1999. “Pollutant Removal in Bioretention Cells with Grass Cover”

Smith, R. A., and Hunt, W.F. III. 2007. “Pollutant removal in bioretention cells with grass cover.” Pp. 1-11 In: Proceedings of the World Environmental and Water Resources Congress 2007.

Sumner, M. E. and W. P. Miller. 1996. Cation Exchange Capacity and Exchange Coefficients. Methods of Soil Analysis, Part 3 – Chemical Methods: 1201-1229

U.S. Army Corps of Engineers (USACE). 2010. Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Atlantic and Gulf Coastal Plain Region (Version 2.0), ed. J. S. Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-10-20. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

USDA-NRCS. 2013. The PLANTS Database. National Plant Data Team, Greensboro, NC 27401-4901 USA. http://plants.usda.gov

Virginia Department of Conservation and Recreation (VA DCR). 2011. Stormwater Design Specification No. 9: Bioretention Version 1.8. Available at http://vwrrc.vt.edu/swc/Non-PBMPSpecsMarch11/VASWMBMPSpec9BIORETENTION.html

Wisconsin Department of Natural Resources. *Storm Water Post-Construction Technical Standards*. http://dnr.wi.gov/topic/stormwater/standards/postconst_standards.html

4.2 Permeable Pavement Systems

<table>
<tr><th colspan="8">Permeable Pavement Systems</th></tr>
<tr><td colspan="8">Definition: Paving systems that capture and temporarily store the 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.</td></tr>
<tr><th colspan="2">Site Applicability</th><th colspan="6">BMP Performance Summary</th></tr>
<tr><th>Land Uses</th><th>Required Footprint</th><th colspan="6">WQ Improvement: Moderate to High</th></tr>
<tr><td rowspan="3">▪ Urban
▪ Suburban
▪ Rural</td><td rowspan="3">Small</td><td colspan="2">TSS[1]</td><td colspan="2">Total N[1]</td><td colspan="2">Bacteria[1]</td></tr>
<tr><td colspan="2">80%</td><td colspan="2">60%</td><td colspan="2">45%</td></tr>
<tr><th colspan="6">Runoff Reductions</th></tr>
<tr><th>Construction Costs</th><th>Maintenance Burden</th><th colspan="3">Rate</th><th colspan="3">Volume</th></tr>
<tr><td>High</td><td>High</td><td colspan="3">Moderate</td><td colspan="3">Moderate</td></tr>
<tr><th colspan="2">Maintenance Frequency:</th><th colspan="6">SWRv</th></tr>
<tr><th>Routine</th><th>Non-Routine</th><th colspan="3">Standard Design</th><th colspan="3">Enhanced Design</th></tr>
<tr><td>2-4 times per year</td><td>Every 2-3 years</td><td colspan="3">5 ft³ per 100 ft²</td><td colspan="3">100% of Sv</td></tr>
<tr><th colspan="2">Advantages/Benefits</th><th colspan="6">Disadvantages/Limitation</th></tr>
<tr><td colspan="2">▪ Reduces runoff volume, attenuates peak runoff rate and outflow
▪ Reduces slick surfaces during rain
▪ Water quality enhancement from filtration of stormwater</td><td colspan="6">▪ Sediment-laden runoff can clog pervious pavement, causing it to fail
▪ Constant pressure in the same spot (constant vehicle braking) can collapse pores, causing pavement to fail
▪ Incorrect installation practices can clog pores</td></tr>
<tr><th colspan="2">Components</th><th colspan="6">Design considerations</th></tr>
<tr><td colspan="2">▪ Open graded pavement mix or pavers with open surfaces
▪ Settling layer
▪ Open-graded base material
▪ Filter fabric
▪ Underdrain (where required)
▪ Subgrade with minimal compaction</td><td colspan="6">▪ Same basic considerations as any paved area
▪ Infiltration rate of native soil determines applicability and need for underdrain
▪ Not appropriate for heavy or high traffic areas
▪ Accessibility, aesthetics, maintainability</td></tr>
<tr><th colspan="2">Installation Considerations</th><th colspan="6">Maintenance Activities</th></tr>
<tr><td colspan="2">▪ Proper construction sequencing and installation is crucial to ensure proper functioning
▪ Subgrade cannot be overly compacted</td><td colspan="6">▪ Vacuum or jet wash to increase pavement life and avoid clogging
▪ Ensure that contributing area is clear of debris and sediment.</td></tr>
</table>

[1] *expected annual pollutant load removal*

Permeable pavement systems represent alternative paving surfaces that capture and temporarily store the design volume by filtering runoff through voids in the pavement surface into an underlying stone reservoir. See Figure 0.12 Permeable pavement section detail
*Source: David Smith, ICPI***Filtered runoff may be collected and returned to the conveyance system, or it may be allowed to partially infiltrate into the soil. Permeable pavement systems are not typically designed to provide stormwater detention of larger storms (e.g., 2 - 50-year), but they may be in some circumstances. Permeable pavement practices shall generally be combined with a separate facility to provide those controls.**

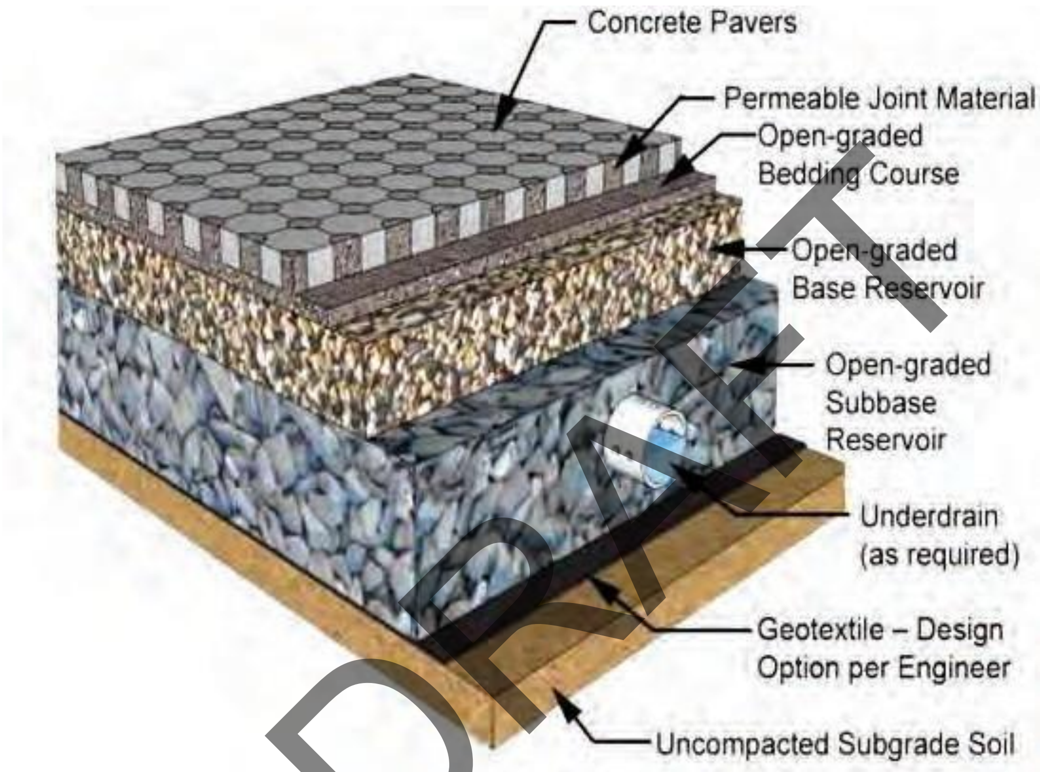

Figure 0.12 Permeable pavement section detail
Source: David Smith, ICPI

Definition. This is a paving system that captures and temporarily stores the 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 the following:

P-1 Porous asphalt (PA)

P-2 Pervious concrete (PC)

P-3 Permeable pavers (PP)

Other surface material variations of permeable pavement that can be part of a permeable pavement system, such as porous rubber, plastic grid pavers, and synthetic turf systems are also encompassed in this section.

Porous Asphalt. Porous asphalt (also known as pervious asphalt) consists of a special open-graded surface course bound together by asphalt cement. The open-graded surface course in a typical porous asphalt installation is 3 to 7 inches thick and has a void ratio of between 15% and 20%. Porous asphalt is thought to have a limited ability to maintain its structure and permeability during hot summer months and, consequently, is currently not recommended for use in coastal South Carolina. If it is used on a development site in the coastal region, it should be carefully monitored and maintained over time.

Pervious Concrete. Pervious concrete (also known as porous concrete) is similar to conventional concrete in structure and form but consists of a special open-graded surface course, typically 4 to 8 inches thick, that is bound together with Portland cement. This open-graded surface course has a void ratio of 15% to 25% (conventional concrete pavement has a void ratio of between 3% and 5%), which gives it a high permeability that is often many times more than that of the underlying native soils, and allows rainwater and stormwater runoff to rapidly pass through it and into the underlying stone reservoir. Although this particular type of permeable pavement surface may not require an underlying base layer to support traffic loads, site planning and design teams may wish to provide it to increase the stormwater storage capacity provided by a pervious concrete system.

Permeable Pavers. Permeable pavers (PP) are solid structural units (e.g., blocks, bricks) that are installed in a way that provides regularly spaced openings through which stormwater runoff can rapidly pass through the pavement surface and into the underlying stone reservoir. The regularly spaced openings, which generally make up between 8% and 20% of the total pavement surface, are typically filled with pea gravel (i.e., ASTM D 448 Size No. 8, 3/8 inch to 1/8 inch). Typical PP systems consist of the pavers, a 1.5- to 3-inch thick fine gravel bedding layer and an underlying stone reservoir.

Design Configurations

There are two types of permeable pavement design configurations:

- **Standard Design.** Practice with a standard underdrain design and no infiltration sump or water quality filter (see Figure 0.13).
- **Enhanced Design.** Practice 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 0.14) or practices with no underdrains that can infiltrate the design storm volume in 48 hours (see Figure 0.15).

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.

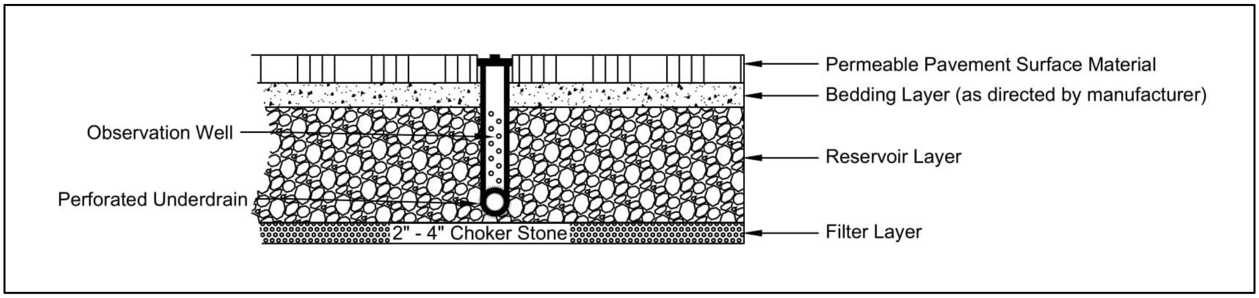

Figure 0.13 Cross section of a standard permeable pavement design.

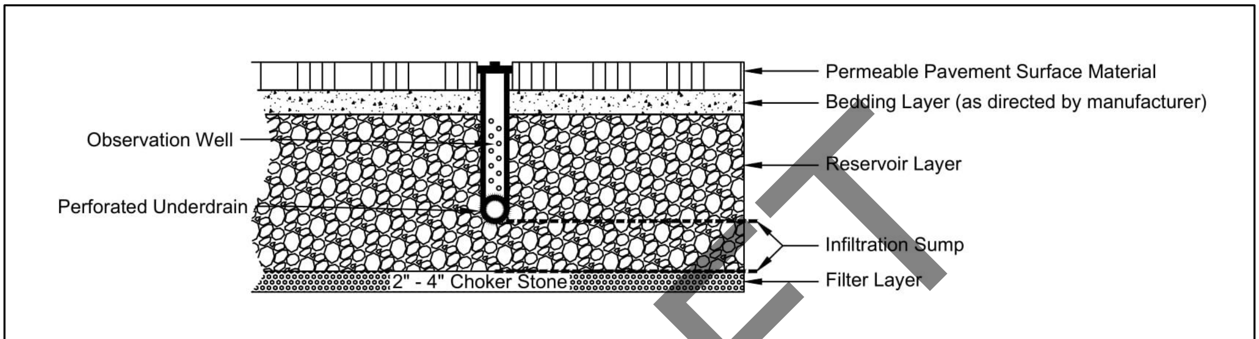

Figure 0.14 Cross section of an enhanced permeable pavement design with an underdrain.

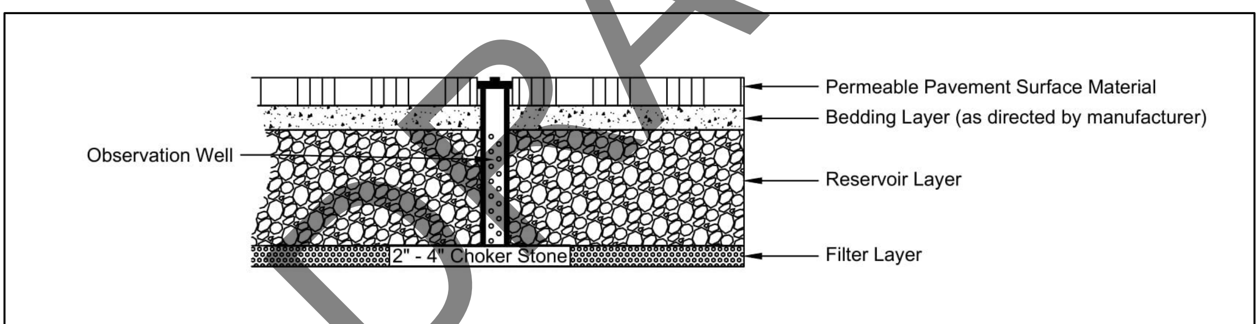

Figure 0.15 Cross section of an enhanced standard permeable pavement design without an underdrain.

4.2.1 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 B Geotechnical Information Requirements for Underground BMPs. 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 4.2.4 Permeable Pavement Design Criteria).

Contributing Drainage Area. The portion of the CDA 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% impervious as possible to reduce sediment loading.

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%. Designers may consider using a terraced design for permeable pavement in areas with steeper slopes (3%–5%). 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 1 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 0.5 feet (preferably 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.

Tidal Impacts. For systems with an underdrain, the underdrain should be located above the tidal mean high water elevation. For entirely infiltration-based systems, the bottom of the stone reservoir should be located above the mean high water elevation. Where this is not possible, portions of the practice below the tidal mean high water elevation cannot be included in the volume calculations.

Setbacks. To avoid the risk of seepage, stormwater cannot flow from the permeable pavement reservoir layer to the traditional pavement base layer, existing structure foundations, or future foundations which may be built on adjacent properties. Setbacks to structures and property lines must be at least 10 feet and adequate waterproofing 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 (PROW). Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the permeable pavement. Permeable pavement in the public right-of-way (PROW) must conform with the State of South Carolina Department of Transportation design specifications. Where conflicts cannot be avoided, follow these guidelines:

- Consider altering the location or sizing of the permeable pavement 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 pavement and the utility to coexist. The permeable pavement 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 pavement.
- If utility functionality, longevity, and vehicular access to manholes can be assured, accept the permeable pavement 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 pavement location and design, it is understood the permeable pavement will be temporarily impacted during utility work, but the utility owner will replace the permeable pavement or, alternatively, install functionally comparable permeable pavement according to the specifications in the current version of this guidebook. Restoration of permeable pavement that is located in the PROW will also conform with the State of South Carolina Department of Transportation design specifications.

Pollutant Hotspot Land Uses. Permeable pavement is not appropriate for certain pollutant-generating sites. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil-water separator or filtering device must be provided, or the areas should be diverted from the permeable pavement.

On sites with existing contaminated soils, infiltration is not allowed. Permeable pavement areas 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 considerable 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 a sod filter strip should be employed (see Section 4.2.3 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.

Economic Considerations. Permeable pavement tends to be expensive relative to other practices, but when the cost of land and traditional paving are included in the calculations, permeable pavement becomes much more competitive. Permeable pavement is very space-efficient, since it combines a useful pavement surface with stormwater management for runoff and, in standard design configurations, water quality treatment.

4.2.2 Permeable Pavement Conveyance Criteria

Permeable pavement designs must include methods to convey larger storms (e.g., 2 - 50-year) to the storm drain system. Conveyance methods include the following:

- 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.

4.2.3 Permeable Pavement Pretreatment Criteria

Pretreatment for most permeable pavement applications is not necessary. Additional pretreatment is recommended if the pavement receives runoff 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 reduce clogging.

4.2.4 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% longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater. On sloped sites, internal check dams or barriers, as shown in Figure 0.16, can be incorporated into the subsurface to encourage infiltration. Barriers may be constructed of concrete, earthen berms, impermeable membranes, or low permeability geotextile. 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 are dependent upon the underlying slope and the saturated hydraulic conductivity, 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.

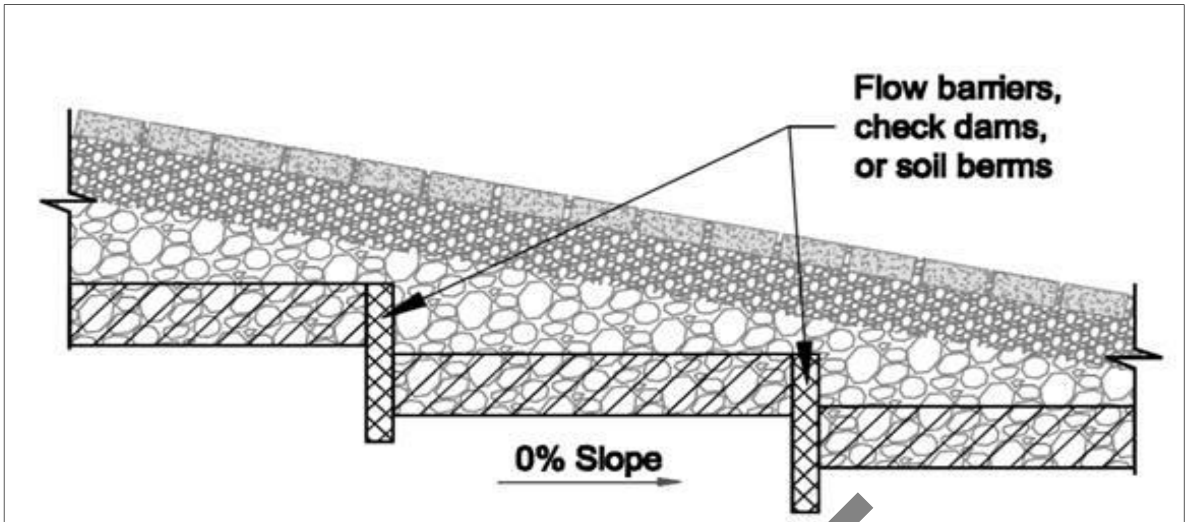

Figure 0.16 Use of flow barriers to encourage infiltration on sloped sites.

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.

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 saturated hydraulic conductivity of in-situ soils, structural requirements of the pavement sub-base, depth to water table, and frost depth conditions (see Section 4.2.1 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 the *<local jurisdiction>*.

- 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 4.2.1 Permeable Pavement Feasibility Criteria). Underdrains can also be used to keep detained stormwater from flooding permeable pavement during extreme rain events. Multiple underdrains are typically necessary for permeable pavement wider than 40 feet, and each underdrain is recommended to 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 three or four rows of 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.

Observation Wells. 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. There should be no perforation within 1 foot of the surface. If the permeable pavement has an underdrain, tie the observation well into any Ts or Ys in the underdrain system. The observation 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 Design). 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 0.18). 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.

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 saturated hydraulic conductivity 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 (10 times) 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 PVC geomembrane liner or equivalent of an appropriate thickness (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 0.14, but designers should consult manufacturer's technical specifications for specific criteria and guidance. Table 0.15 provides 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 0.14 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: 15–20% Thickness: Typically 4–8 inches Compressive strength: 2.8–28 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. Requires certified supplier and installer.
Porous Asphalt (PA)	Void content: 15–20% Thickness: Typically 3–7 inches (depending on traffic load) Open void fill media: None	Reservoir layer required to support the structural load. Requires certified supplier and installer.

Table 0.15 Material Specifications for Typical Layers Beneath the Pavement Surface

Material	Specification	Notes
Bedding Layer	PC: 3–4 inches of No. 57 stone if No. 2 stone is used for Reservoir Layer PA: 3–4 inches of No. 57 stone PP: Follow manufacturer specifications	ASTM D448 size No. 57 stone (i.e., 1/2 to 1 1/2 inches 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 (i.e., 1/2 to 1 1/2 inches in size); No. 2 Stone (i.e., 3/4 to 3 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 *<local jurisdiction>*.
Underdrain	Use 4- to 6-inch diameter perforated PVC pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications), with 3 or 4 rows of 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 for both sides and/or bottom that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher than (10 times) the soil subgrade permeability. Low-permeability geotextile fabric may be used as a check dam material.	
Impermeable Liner (optional)	Where appropriate, use PVC geomembrane liner or equivalent.	
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 to support 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 (i.e., 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 the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (less than 4%), they may need to be compacted to at least 95% 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 saturated hydraulic conductivity 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 0.4.

Equation 0.4 Reservoir Layer or Infiltration Sump Depth

$$d_p = \frac{\left(\frac{P \times Rv_I \times CDA}{A_p}\right) - (K_{sat} \times t_f)}{\eta_r}$$

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	=	0.95 (runoff coefficient for impervious cover)
CDA	=	total contributing drainage area, including permeable pavement surface area (ft^2)
A_p	=	permeable pavement surface area (ft^2)
K_{sat}	=	field-verified saturated hydraulic conductivity for the subgrade soils (ft/day). If an impermeable liner is used in the design then $K_{sat} = 0$.
t_f	=	time to fill the reservoir layer (day) (assume 2 hours or 0.083 day)

η_r	=	0.4 (effective porosity for the reservoir layer)

This equation makes the following design assumptions:

- The CDA does not contain pervious areas.
- If the subgrade will be compacted to meet structural design requirements of the pavement section, the measured saturated hydraulic conductivity shall be based on measurement of the subgrade soil subjected to the compaction requirements.
- The porosity (η_r) for No. 57 stone is 0.4.

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 0.5 can be used to determine the drawdown time in the reservoir layer or infiltration sump.

Equation 0.5 Drawdown Time

$$t_d = \frac{d_p \times \eta_r}{K_{sat}}$$

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	=	0.4 (effective porosity for the reservoir layer)
K_{sat}	=	field-verified saturated hydraulic conductivity for the subgrade soils (ft/day). If an impermeable liner is used in the design, then $K_{sat} = 0$.

For designs with underdrains, the drawdown time should be determined using the hydrologic 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 0.6.

Equation 0.6 Permeable Pavement Storage Volume

$$Sv = A_p[(d_p \times \eta_r) + K_{sat} \times t_f]$$

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	=	0.4 (effective porosity for the reservoir layer)
A_p	=	permeable pavement surface area (ft^2)
K_{sat}	=	field-verified saturated hydraulic conductivity for the subgrade soils (ft/day). If an impermeable liner is used in the design then $K_{sat} = 0$.
t_f	=	time to fill the reservoir layer (days) (assume 2 hours or 0.083 days)

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 4.2.2 Permeable Pavement Conveyance Criteria).

4.2.5 Permeable Pavement Landscaping Criteria

Permeable pavement does not have any landscaping needs. 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, and other plant matter will inadvertently clog the paving surface. Bioretention areas (see Section 4.1 Bioretention) may be a good design option to meet these landscaping goals.

4.2.6 Permeable Pavement Construction Sequence

Experience has shown that proper installation is 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 limits 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 California Bearing Ratio 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 remedies 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, 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 before the permeable pavement can be installed to establish that design rates have been achieved.
- Finally, if it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, 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 should 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 remedies are similar to those discussed for heavy equipment compaction.

- If it is possible, restrict the invert of the sediment trap or basin to 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 Contributing Drainage Area.** Construction of the permeable pavement should only begin after the entire CDA has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow and do not install frozen bedding materials.

Step 2: **Install Soil Erosion and Sediment Control Measures for the Permeable Pavement.** 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% 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 4.12.

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 230°F and 260°F, 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 D1664. If the estimated coating area is not above 95%, 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 5 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 (0.5 inch or greater) or artificial flooding to determine if the facility is draining properly.

Pervious Concrete Installation. The basic installation sequence for pervious concrete is outlined by the National Ready Mixed Concrete Association (NRMCA) (NRMCA, 2004). Concrete installers are required to be certified by 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 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 (0.5 inch or greater) or artificial flooding, to determine if the facility is draining properly.

Permeable Interlocking Concrete Paver Installation. 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 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 two passes are in vibratory mode, with the final two passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
- 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 D448 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-pound-foot, 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 (0.5 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. ASTM test C1781 or C1701 must be performed to ensure initial pavement permeability of at least 6 inches per hour. 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.

Construction phase inspection checklist for permeable pavement practices can be found in Appendix E Construction Inspection Checklists.

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

- Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
- The CDA should be stabilized prior to directing water to the permeable pavement area.
- Check the aggregate material to confirm it is clean and washed, meets specifications and is installed to the correct depth. Aggregate loads that do not meet the specifications or do not appear to be sufficiently washed may be rejected.
- Check elevations (i.e., 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, 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.

4.2.7 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
- Resealing
- Resurfacing
- 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 0.16.

Table 0.16 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 0.5 inch of rainfall. Conduct any needed repairs or stabilization.
Once every 1–2 months during the growing season	▪ Mow grass in grid paver applications (clippings should be removed from the pavement area).
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 ▪ Remove weeds as needed.
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 0.5 inch to 1 inch above the pavement surface to prevent damage to the paving blocks or turf. Porous asphalt, pervious concrete, and some permeable pavers can be plowed similarly 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. Maintenance inspection checklists for permeable pavements and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

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 the <*local jurisdiction*> 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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 local, state, and federal law.

4.2.8 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% retention value for the storage volume (Sv) provided by the practice (Table 0.17). Since the practice gets 100% retention value, it is not considered an accepted total suspended solids (TSS) treatment practice.

Table 0.17 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 General Retention Compliance Calculator, 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 5.0 cubic feet per 100 square feet of practice area and are an accepted TSS removal practice for the storage volume (Sv) provided by the practice (Table 0.18).

Table 0.18 Standard Permeable Pavement Retention Value and Pollutant Removal

Retention Value	5.0 cubic feet per 100 square feet of practice
Accepted TSS Treatment Practice	Yes

The practice must be sized using the guidance detailed in Section 4.2.4 Permeable Pavement Design Criteria.

Permeable pavement also contributes to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the storage volume (Sv) achieved by the practice from the total runoff volumes for the 2-year through the 100-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN 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.

4.2.9 References

American Association of State Highway and Transportation Officials (AASHTO). 1993. AASHTO Guide for Design of Pavement Structures, 4th Edition with 1998 Supplement. Washington, D.C.

ASTM C1701 / C1701M-17a, Standard Test Method for Infiltration Rate of In Place Pervious Concrete, ASTM International, West Conshohocken, PA, 2017, www.astm.org

ASTM C1781 / C1781M-15, Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems, ASTM International, West Conshohocken, PA, 2015, www.astm.org

ASTM D1664-80(1985), Test Method for Coating and Stripping of Bitumen-Aggregate Mixtures (Withdrawn 1992), ASTM International, West Conshohocken, PA, 1985, www.astm.org

ASTM D448-12(2017), Standard Classification for Sizes of Aggregate for Road and Bridge Construction, ASTM International, West Conshohocken, PA, 2017, www.astm.org

Atlanta Regional Commission (ARC). 2001. "Porous Concrete." Georgia Stormwater Management Manual. Volume 2. Technical Handbook. Section 3.3.7. Atlanta Regional Commission. Atlanta, GA. Available Online at http://www.georgiastormwater.com/

Atlanta Regional Commission (ARC). 2001. "Modular Porous Paver Systems." Georgia Stormwater Management Manual. Volume 2. Technical Handbook. Section 3.3.8. Atlanta Regional Commission. Atlanta, GA. Available Online at http://www.georgiastormwater.com/

Brown, R. and W. Hunt. 2009. "Improving Exfiltration from BMPs: Research and Recommendations." North Carolina Cooperative Extension Service Bulletin. Urban Waterways Series.

Hunt, W. and K. Collins. 2008. "Permeable Pavement: Research Update and Design Implications." North Carolina Cooperative Extension Service Bulletin. Urban Waterways Series. AG-588-14. North

Carolina State University. Raleigh, NC. Available Online: http://www.bae.ncsu.edu/stormwater/PublicationFiles/PermPave2008.pdf

Jackson, N. 2007. Design, Construction and Maintenance Guide for Porous Asphalt Pavements. National Asphalt Pavement Association (NAPA), Porous Asphalt Pavements for Stormwater Management: Design, Construction, and Maintenance Guide (IS-131). Lanham, MD, 2008. http://store.asphaltpavement.org/index.php?productID=179

National Ready Mixed Concrete Association (NRMCA). 2004. Concrete in Practice – 38: Pervious Concrete. Silver Spring, MD. http://nrmca.org/aboutconcrete/cips/38p.pdf

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

Virginia DCR Stormwater Design Specification No. 7: Permeable Pavement Version 1.7. 2010.

4.3 Infiltration

<table>
<tr><th colspan="6">Infiltration</th></tr>
<tr><td colspan="6">Definition: Practices that capture and temporarily store the design storm volume before allowing it to infiltrate into the soil over a three-day period.</td></tr>
<tr><th colspan="2">Site Applicability</th><th colspan="4">BMP Performance Summary</th></tr>
<tr><th>Land Uses</th><th>Required Footprint</th><th colspan="4">WQ Improvement: Moderate to High</th></tr>
<tr><td rowspan="3">▪ Urban
▪ Suburban
▪ Rural</td><td rowspan="3">Small</td><th colspan="2">TSS[1]</th><th>Total N[1]</th><th>Bacteria[1]</th></tr>
<tr><td colspan="2">75-80%</td><td>45-65%</td><td>65%</td></tr>
<tr><th colspan="4">Runoff Reductions</th></tr>
<tr><th>Construction Costs</th><th>Maintenance Burden</th><th colspan="2">Rate</th><th colspan="2">Volume</th></tr>
<tr><td>Moderate</td><td>Moderate</td><td colspan="2">Moderate</td><td colspan="2">Low</td></tr>
<tr><th colspan="2">Maintenance Frequency:</th><th colspan="4">SWRv</th></tr>
<tr><th>Routine</th><th>Non-Routine</th><th colspan="2">Basin</th><th colspan="2">Trench</th></tr>
<tr><td>Quarterly</td><td>Every 5-10 years</td><td colspan="2">100% of Sv</td><td colspan="2">100% of Sv</td></tr>
<tr><th colspan="2">Advantages/Benefits</th><th colspan="4">Disadvantages/Limitation</th></tr>
<tr><td colspan="2">▪ Excellent in impervious CDAs
▪ Helps restore pre-development hydrologic conditions through groundwater recharge
▪ Reduces runoff rates, volumes, and pollutant loads
▪ Attractive landscaping features
▪ Good for small sites with porous soils</td><td colspan="4">▪ CDA should less than 2 acres.
▪ Potential for groundwater contamination
▪ High clogging potential;
▪ Not for sites with fine soils (clays/silts) in CDA
▪ Cannot be used in karst bedrock
▪ Geotechnical testing required, two borings per facility</td></tr>
<tr><th colspan="2">Components</th><th colspan="4">Design considerations</th></tr>
<tr><td colspan="2">▪ Pretreatment
▪ Conveyance system
▪ Ponding area
▪ Soils/Filter Media/Mulch
▪ Observation Well/Monitoring Port
▪ Plants</td><td colspan="4">▪ Maximum ponding depth 18 inches
▪ Planting bed depths between 18-36 inches
▪ Depth to seasonal high water table must be at least 6 inches
▪ Must infiltrate within 72 hours
▪ Underdrain system may be needed</td></tr>
<tr><th colspan="6">Maintenance Activities</th></tr>
<tr><td colspan="2">▪ Inspect for clogging
▪ Replace mulch as needed to maintain depth of mulch</td><td colspan="4">▪ Replace plant material as needed
▪ Replace soil if it becomes clogged
▪ Clean conveyance system(s)</td></tr>
</table>

[1] *expected annual pollutant load removal*

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. If properly designed, they can provide significant reductions in post-construction stormwater runoff rates, volumes, and pollutant loads on development sites. See Figure 0.17**.**

Figure 0.17 Infiltration in Median Strip

Definition. Practices that capture and temporarily store the design storm volume before allowing it to infiltrate into the soil over a three-day period. 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-verified saturated hydraulic conductivity is sufficient.

Design variants include the following:

I-1 Infiltration trench

I-2 Infiltration basin

Infiltration Trenches: Infiltration trenches are excavated trenches filled with stone. Stormwater runoff is captured and temporarily stored in the stone reservoir, where it is allowed to infiltrate into the surrounding and underlying native soils. Infiltration trenches can be used to "receive" stormwater runoff from contributing drainage areas of up to 2 acres in size and should only be used on development sites where sediment loads can be kept relatively low (see Figure 0.18 and Figure 0.19).

Infiltration Basins: Infiltration basins are shallow, landscaped excavations filled with an engineered soil mix. They are designed to capture and temporarily store stormwater runoff in the engineered soil mix, where it is subjected to the hydrologic processes of evaporation and transpiration, before being allowed to infiltrate into the surrounding soils. They are essentially non-underdrained bioretention areas and should also only be used on drainage areas up to 5 acres where sediment loads can be kept relatively low (See Figure 0.20).

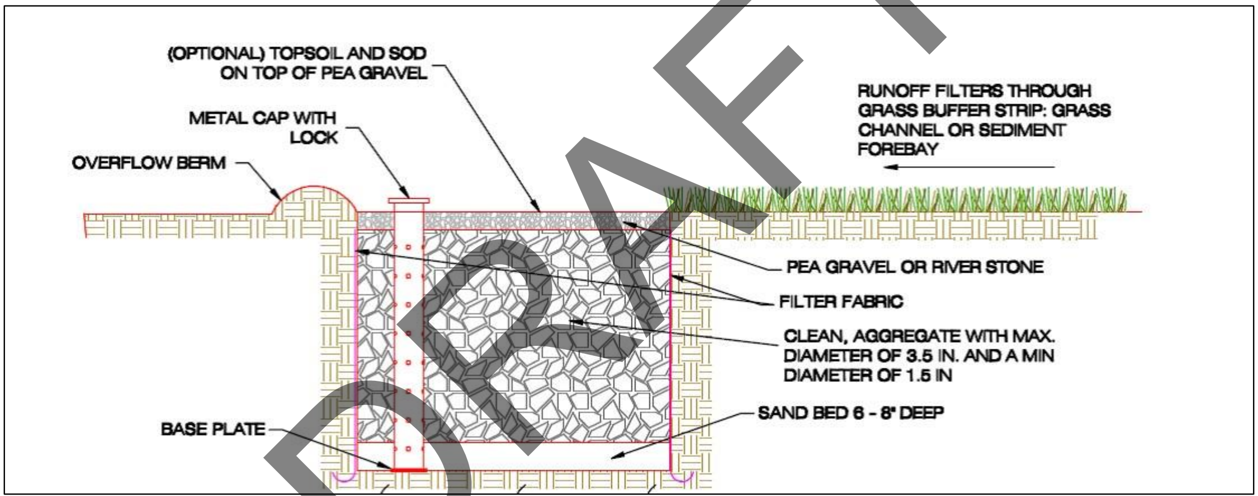

Figure 0.18 Example of an infiltration trench.

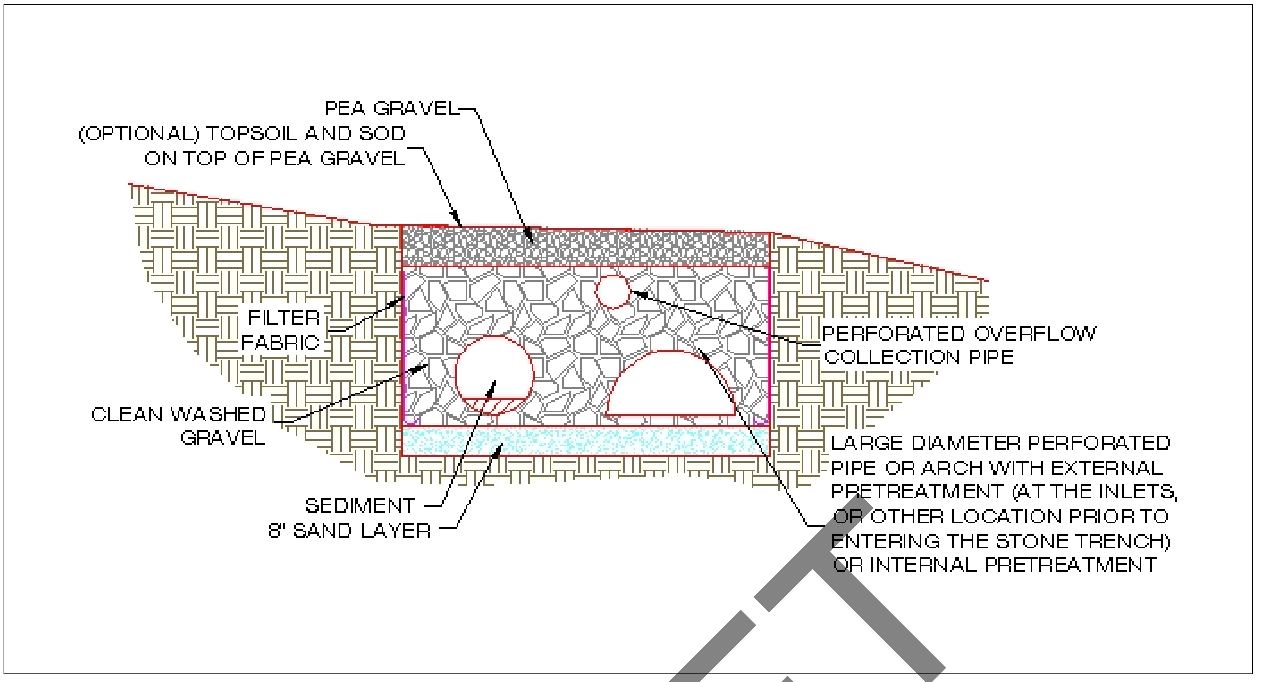

Figure 0.19 Infiltration section with supplemental pipe storage.

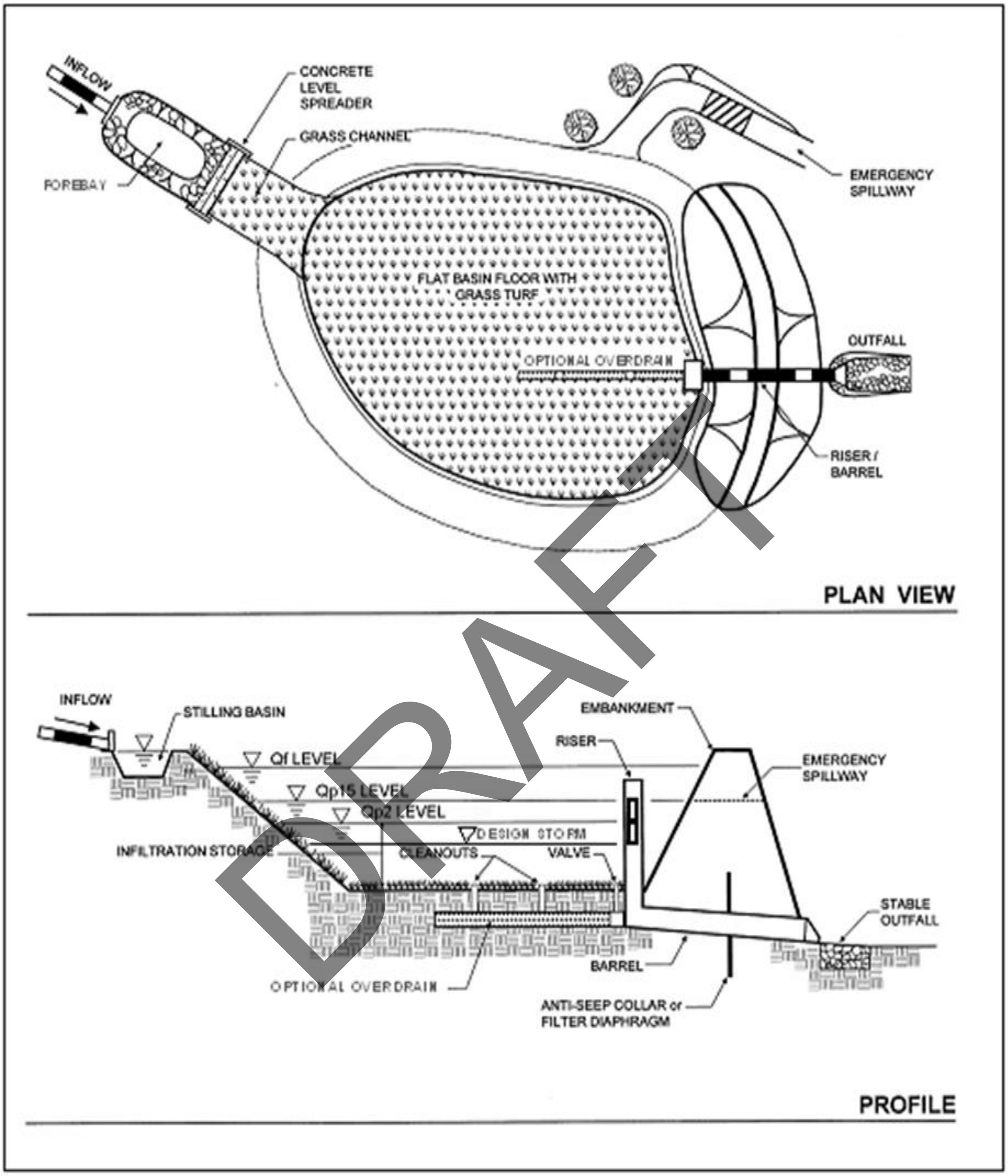

Figure 0.20 Example of an infiltration basin.

4.3.1 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 HSG A or B soils, shown on the U.S. Department of Agriculture's 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 to regulation under the Federal Underground Injection Control 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 https://www.epa.gov/sites/production/files/2015-10/documents/epamemoinfiltrationclassvwells.pdf for EPA's clarification for stormwater infiltration.

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

Site Topography. The infiltration practice shall not be located on slopes greater than 6%, 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%.

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

Minimum Depth to Water Table. A minimum vertical distance of 0.5 feet must be provided between the bottom of the infiltration practice.

Tidal Impacts. The bottom of an infiltration practice should be located above the tidal mean high water elevation. Where this is not possible, portions of the practice below the tidal mean high water elevation cannot be included in the volume calculations.

Soils. Initially, soil infiltration rates can be estimated from NRCS soil data for feasibility purposes, but designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix B Geotechnical Information Requirements for Underground BMPs for their design.

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 saturated hydraulic conductivity 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. To avoid the risk of seepage, stormwater cannot flow from infiltration practices to traditional pavement base layer, existing structure foundations, or future foundations which may be built on adjacent properties. Setbacks to structures and property lines must be at least 10 feet and adequate waterproofing 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). In locations where the surface soil consists of highly permeable soils with little separation of the infiltration trench or basin bottom, the extent of ground water mounding should be considered. Mounding can occur in areas where infiltrating water intersects a groundwater table and the rate of water entering the subsurface is greater than the rate at which water is conveyed away from the infiltration system (MPCA, 2019). Ground water mounding may impact building foundations, soil stability, underground utilities and potentially on-site treatment systems (septic leach beds).

All setbacks must be verified by a professional geotechnical engineer registered in the State of South Carolina.

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 PROW. Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the infiltration BMP. Infiltration BMPs in the PROW will also conform with the State of South Carolina Department of Transportation design specifications. 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 key design features may need to be moved, added, or deleted.
- Evaluate the relocation of the existing utility and install an optimally placed and sized 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. At the conclusion of this work, the utility owner will replace the infiltration BMP or, alternatively, install a functionally comparable infiltration BMP according to the specifications in the current version of this guidebook. If the infiltration BMP is located in the PROW the infiltration BMP restoration will also conform with the State of South Carolina Department of Transportation design specification.

Pollutant 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. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil-water separator or filtering device must be provided. These pretreatment facilities should be monitored and maintained frequently to avoid negative impacts to the infiltration area and groundwater.

On sites with existing contaminated soils, infiltration is not allowed.

Economic Considerations. Infiltration practices do require a designated space on the site, which in space-constrained areas, may reduce available building space. However, infiltration practices have a relatively low construction cost, and high space efficiency. In some cases, they can even be incorporated into the detention design or landscaped areas

4.3.2 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 and conveyance 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 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.

4.3.3 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% of the inflow in every facility:

- Grass channel
- Grass filter strip (minimum 20 feet and only if sheet flow is established and maintained)
- Forebay or sump pit (must accommodate a minimum 15% 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 0 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 0 Proprietary Practices.

If the basin serves a CDA greater than 20,000 square feet, a forebay, sump pit, 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).

4.3.4 Infiltration Design Criteria

Geometry. Where possible, an infiltration practice should be designed to be wider than it is deep, to avoid classification as a Class V injection well. For more information on Class V wells see https://www.epa.gov/sites/production/files/2015-10/documents/epamemoinfiltrationclassvwells.pdf

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

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.

Observation Wells. All infiltration practices must include at least one observation well. The observation well is used to observe the rate of drawdown within the infiltration practice 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. There should be no perforation within 1 foot of the surface. The observation well should extend vertically to the bottom of the stone layer and extend upward to the top of ponding.

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 inches in diameter).

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 (10 times) higher 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 0.19.

Table 0.19 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, double-washed 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 three or four rows of 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 inches in diameter)	
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 (10 times) higher 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 CDA, 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 0.7) or trench with an underground reservoir (Equation 0.8).

Equation 0.7 Maximum Surface Basin Depth for Infiltration Basins

$$d_{max} = K_{sat} \times t_d$$

Equation 0.8 Maximum Underground Reservoir Depth for Infiltration Trenches

$$d_{max} = \frac{(K_{sat} \times t_d)}{\eta_r}$$

where:

d_{max}	=	maximum depth of the infiltration practice (ft)
K_{sat}	=	field-verified saturated hydraulic conductivity for the native soils (ft/day)
t_d	=	maximum drawdown time (day) (normally 3 days)
η_r	=	available porosity of the stone reservoir (assume 0.4)

These equations make the following design assumptions:

- **Stone Layer Porosity.** A porosity value of 0.4 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 0.20 and use whichever value is less for the subsequent design.

Table 0.20 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 0.9 or Equation 0.10.

Equation 0.9 Surface Basin Surface Area for Infiltration Basins

$$SA = \frac{DesignStorm}{d + (K_{sat} \times t_f)}$$

Equation 0.10 Underground Reservoir Surface Area for Infiltration Trenches

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

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 0.4)
d	=	infiltration depth (ft) (maximum depends on the scale of infiltration and the results of Equation 0.7 or Equation 0.8)
K_{sat}	=	field-verified saturated hydraulic conductivity 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 (i.e., 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 Sv of the practice (see Section 3.8.8 Infiltration Stormwater Compliance Calculations). Sv can be determined by rearranging Equation 0.9 and Equation 0.10 to yield Equation 0.11 and Equation 0.12.

Equation 0.11 Storage Volume Calculation for Surface Basin Area for Infiltration Basins

$$Sv = SA \times [d + (K_{sat} \times t_f)]$$

Equation 0.12 Storage Volume Calculation for Underground Reservoir Surface Area for Infiltration Trenches

$$Sv = SA \times [(\eta_r \times d) + (K_{sat} \times t_f)]$$

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.

4.3.5 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.

4.3.6 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. Second, 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 limits of disturbance during construction.
- When this is unavoidable, there are several possible remedies 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 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 infiltration practice 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, 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 should 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 remedies are similar to those discussed for heavy equipment compaction. If it is possible, restrict the invert of the sediment trap or basin to 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 be 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 CDAs 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.

4.3.7 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 layer by organic matter and sediment. The following design features can minimize the risk of clogging:

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

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

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 0.21. Where possible, facility maintenance should be integrated into routine landscaping maintenance tasks.

Table 0.21 Typical Maintenance Activities for Infiltration Practices

Schedule	Maintenance Activity
Quarterly	▪ Ensure that the CDA, inlets, and facility surface are clear of debris. ▪ Ensure that the CDA is stabilized. Perform spot-reseeding if where needed. ▪ Remove sediment and oil/grease from inlets, 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 0.5 inch in depth. Standing water observed in the well after 3 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.

<local jurisdiction>'s maintenance inspection checklist for infiltration systems and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

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 the *<local jurisdiction>* 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of

Deeds in the County office. 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 local, state, and federal law.

4.3.8 Infiltration Stormwater Compliance Calculations

Infiltration practices receive 100% retention value for the storage volume (Sv) provided by the practice (Table 0.22). Since the practice gets 100% retention value, it is not considered an accepted total suspended solids (TSS) treatment practice.

Table 0.22 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 4.3.4 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 storage volume (Sv) from the total runoff volume for the 2-year through the 100-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN 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.

4.3.9 References

Atlanta Regional Commission (ARC). 2001. “Infiltration Trench.” Georgia Stormwater Management Manual. Volume 2. Technical Handbook. Section 3.2.5. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www.georgia stormwater.com/.

Burchell, M., W. Hunt and W.D. Price. 2013. Dune Infiltration Systems for Reducing Stormwater Discharge to Coastal Recreational Beaches. AG-781. NC Cooperative Extension. Available online at http://www.bae.ncsu.edu/people/faculty/mrburche/publications/ag-781- dune.pdf

Chesapeake Stormwater Network. 2009. CSN Technical Bulletin No. 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed, Version 2.0.

Hirschman, D., Collins, K., and T. Schueler. 2008. Technical Memorandum: The Runoff Re- duction Method. Center for Watershed Protection and Chesapeake Stormwater Network. Ellicott City, MD.

Minnesota Pollution Control Agency (MPCA). 2009. “Infiltration Practices.” Minnesota Stormwater Manual. Chapter 12. Minnesota Pollution Control Agency. Available Online: Available Online: https://stormwater.pca.state.mn.us/index.php?title=Main_Page

Schueler, T., D. Hirschman, M. Novotney, and J. Zielinski. 2007. Urban Stormwater Retro- fit Practices, Version 1.0, Urban Subwatershed Restoration Manual No. 3.

Virginia Department of Conservation and Recreation (VA DCR). 2011. Stormwater De- sign Specification No. 8: Bioretention Version 1.8. Available at http://vwrrc.vt.edu/ swc/april_22_2010_update/DCR_BMP_Spec_No_9_BIORETENTION_FinalDraft_v1- 8_04132010.htm

U.S. Environmental Protection Agency. 2008. Memorandum: Clarification of which storm- water infiltration practices/technologies have the potential to be regulated as "Class V" wells by the Underground Injection Control Program. From: Linda Boornazian, Director, Water Permits Division (MC 4203M); Steve Heare, Director, Drinking Water Protection Division (MC 4606M)..

4.4 Green Roofs

Green Roofs					
Definition: Practices that capture and store rainfall in an engineered growing media installed over a waterproof membrane that is designed to support plant growth on the roof of a building or other structure.					

Site Applicability		BMP Performance Summary		
Land Uses	Required Footprint	WQ Improvement: Moderate to High		
▪ Urban ▪ Suburban	**Small**	TSS[1]	Total N[1]	Bacteria[1]
		80%	45%	45%
		Runoff Reductions		

Construction Costs	Maintenance Burden	Rate	Volume
High	Low	Moderate	Low
Maintenance Frequency:		***SWRv***	
Routine	Non-Routine	Unirrigated	Irrigated
Semi-annually	As needed	100% of *Sv*	50% of *Sv*

Advantages/Benefits	Disadvantages/Limitation
▪ Reduces runoff rates and pollutant loads ▪ Reduces runoff volume ▪ Energy savings: keep buildings cool, prolongs roof life ▪ Retention and water quality treatment ▪ Possible amenity space for public or users ▪ Sound absorption ▪ Life cycle costs comparable to traditional roof	▪ For retrofits, strengthening structure may be required ▪ If leaks occur, may be harder to trace ▪ Design and installation require specialized knowledge ▪ Typically applied on flat roofs (1-2% pitch) ▪ Installation costs higher than for traditional roof

Components	Design considerations
▪ Vegetation that thrives in rooftop climate. ▪ Engineered planting medium (not soil). ▪ Filter layer. ▪ Containment (Modular systems - plant containers; Non-modular systems - barriers at roof perimeter/drainage structures). ▪ Drain layer, sometimes with built-in water reservoirs. ▪ Water proofing layer or roof membrane with root repellant.	▪ Good waterproofing material and installation are essential. ▪ Materials used must be lightweight. ▪ Building structure must be able to support saturated weight. ▪ Roofs with moderate to flat slopes are most appropriate. Maximum roof slope of 15%.

Maintenance Activities	
▪ Watering and fertilization until well-established ▪ Occasional weeding	▪ Inspection for proper drainage and plant health ▪ Ordinary life cycle roof replacement

[1] *expected annual pollutant load removal*

Green roofs are practices that capture and store rainfall in an engineered growing media that is designed to support plant growth (see Figure 0.21**). 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 or fertilization after vegetation is initially established.**

Green roofs are typically not designed to provide stormwater detention of larger storms (e.g., 2 - 50-year) although some intensive green roof systems may be designed to meet these criteria. Green roof designs should generally be combined with a separate facility to provide large storm controls.

Figure 0.21 Green Roof
Photo: Center for Watershed Protections

Definition. Practices that capture and store rainfall in an engineered growing media installed over a waterproof membrane that is designed to support plant growth on the roof of a building or other structure. 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. 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 8 inches thick and are designed to have minimal maintenance requirements.

G-2 Intensive green roofs have a growing media layer that typically ranges from 8 to 48 inches thick.

Green roofs are typically not designed to provide stormwater detention of larger storms (e.g., 2 - 50-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.

4.4.1 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 4.4.4 Green Roof Design Criteria for more information on structural design considerations.

Hurricane-Prone Areas. As South Carolina is subject to hurricanes, some may be concerned about the durability of green roofs in high winds. Having good vegetative cover and root growth in the growing media is the most effective way to reduce wind erosion of the media during high winds. New green roofs where the plants have not yet deeply rooted are the most susceptible to plant damage and media blow-off in a hurricane. Therefore, it is best to install a green roof three or more months prior to hurricane season, to allow enough time for the plants to be established.

Roof Pitch. Green roof storage volume is maximized on relatively flat roofs (a pitch of 1% to 2%). Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growing media. Green roofs can be installed on rooftops with slopes up to 30% 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% would be considered a green wall, which is not specifically identified as a stormwater 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, permanent access to the roof must be available to deliver construction materials and perform routine maintenance. A temporary ladder is not sufficient for access to the roof. 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 contributing drainage area (CDA) to a green roof be limited to the green roof itself. In cases where there will be additional CDA, the designer must provide sufficient design detail showing distribution of this additional runoff throughout the green roof area to prevent erosion or overloading of the roof growing media with the use of level spreaders, splash pads, perforated piping, or other flow dissipation techniques. The absolute maximum CDA to a green roof shall be no more than 100% larger than the area of the green roof (e.g., a 1,000-square-foot green roof can have no more than 1,000 square feet of additional impervious cover draining to it).

Local Building Codes. The green roof design must comply with the local building codes with respect to roof drains and emergency overflow devices. Additionally, a structural engineer should certify that the design complies with structural building codes. For green roofs installed on historic buildings or in historic districts, consult local building codes and architectural review criteria to determine if any special requirements exist for green roof design or maintenance.

Additionally, a State of South Carolina registered structural engineer must certify that the design complies with State building structural codes. This is true for new construction as well as retrofit projects.

Economic Considerations. Green roofs tend to be one of the most expensive BMPs on a per cubic foot captured basis. However, a green roof allows stormwater management to be achieved in otherwise unused space, a major benefit in space-constrained locations. Further, green roofs provide many other non-stormwater services with economic benefits, including increased insulation and roof life expectancy

4.4.2 Green Roof Conveyance Criteria

The green roof drainage layer (refer to Section 4.4.4 Green Roof Design Criteria) 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.

4.4.3 Green Roof Pretreatment Criteria

Pretreatment is not necessary for green roofs.

4.4.4 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 E2397 / E2397M-15, Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems (ASTM, 2015).

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 0.22).

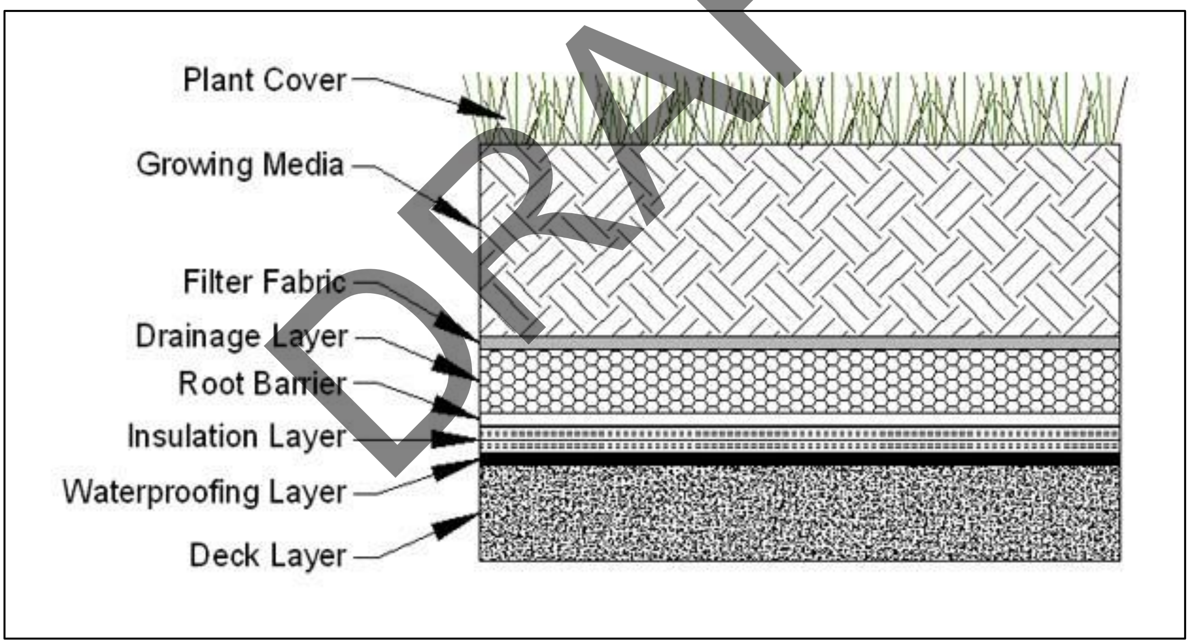

Figure 0.22 Typical layers for a green roof.
Note: the relative placement of various layers may vary depending on the type and design of the green roof system.

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. Electric Field Vector Mapping (EFVM®) or other leak detection techniques are strongly recommended as part of the green roof installation process. In the case of EFVM, the deck material must be conductive. If it is not, an additional conductive medium may need to be added on top of the deck. Other leak detection systems may require additional materials between the deck layer and the waterproofing layer.
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% 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 that 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 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 0.25–1.5 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 (ASTM, 2017). 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 (ASTM E2396, 2015 and ASTM E2398, 2015).

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 3–8 inches deep. The recommended growing media for extensive green roofs is typically composed of approximately 70%–80% lightweight inorganic materials, such as expanded slates, shales or clays; pumice; scoria; or other similar materials. The media must contain no more than 30% organic matter, normally well-aged compost (see Appendix C Soil Compost Amendment Requirements). 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. It is advisable to mix the media in a batch facility prior to delivery to the roof. 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 (although the organic material limit still applies), and it is often much greater in depth (e.g., 8–48 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 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 4.4.4 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 applications, 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 0.23 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 0.23 Extensive Green Roof Material Specifications

Material	Specification
Roof	Structural capacity must conform to ASTM E2397, *Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems*. In addition, use standard test methods ASTM E2398, *Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Vegetated (Green) Roof Systems* and ASTM E2399, *Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetative (Green) Roof Systems*.
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 0.25–1.5 inches thick for extensive designs. The drainage layer should consist of synthetic or inorganic materials (e.g., gravel, 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 local construction codes.
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 $\geq$ 8 oz/yd^2. Puncture resistance as per ASTM D4833 $\geq$ 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 $\geq$ 0.06mm $\leq$ 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%–80% lightweight inorganic materials and a maximum of 30% organic matter (e.g., well-aged compost). Material makeup of the growing media must be provided. Media must provide sufficient nutrient and water holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM E2396. An acceptable emerging industry practice combines the drainage layer with the growing media layer.
Plant Materials	*Sedum*, herbaceous plants, and perennial grasses that are shallow-rooted, low maintenance, and tolerant of full and direct sunlight, drought, wind, and frost. See ASTM E2400, *Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems*.

Rock Wool and Contributing Drainage Area. As stated in Section 4.2.1 above, in cases where the green roof CDA extends beyond the green roof itself, the design must include sufficient distribution or dissipation of this additional runoff throughout the green roof. Typically, to provide sufficient distribution, the additional roof area must have a higher elevation than the green roof, so that gravity flow will allow the runoff to reach the green roof. If rock wool is used as the drainage layer for the green roof, however, the additional CDA may be located at the same elevation as the base of the green roof.

Rock wool, also referred to as mineral wool, is a product that has somewhat recently begun to be incorporated as the drainage layer for green roofs, as it absorbs water, but still allows excess water to drain. The unique absorptive properties of rock wool allow it to absorb runoff from an adjacent roof surface, which means the additional CDA to the green roof does not need to be at a higher elevation than the green roof. The following caveats and requirements apply to this approach:

- No roof drains can be present in the additional contributing roof area, as they will provide a preferential flow path that bypasses the green roof.
- The drainage layer cannot include an air layer. The rock wool drainage layer must be in direct contact with the roof. Designs that include an air layer and rely on "wicking tongues" to capture the additional CDA are not acceptable.
- Channels to facilitate overflow and eliminate rooftop flooding may be incorporated into the rock wool:
    - The maximum channel width is 0.5 inches. Water contact with the sides of the channel is essential to ensure complete capture of smaller storm events. Wider channels may allow too much bypass.
    - Perforated pipe and other designs that limit water contact with the rock wool on the sides of the channels are not acceptable.
    - Channels must be evenly distributed throughout the green roof and be spaced no closer than one channel every 2.5 feet.

The runoff flow path from the contributing roof area must be less than or equal to the length of the channels.

Solar Panels and Other Structures. Occasionally, structures such as solar panels or HVAC systems must be installed above a green roof. These structures can be incorporated into a green roof design with no adverse effects to the retention value assigned to the green roof if specific design requirements for runoff disbursement, maintenance access, and sun/wind exposure are incorporated, including the following:

- Structures above the green roof must be no more than 6.5 feet wide.
- Structures must have a minimum 3-foot separation between them.
- The lower edge of the structure must be at least 1 foot above the top of the green roof, and the upper edge must be at least 2.5 feet above the top of the green roof. This allows for at least a 15-degree tilt. For flatter installations, the lower edge would need to be raised to ensure that the 2.5-foot minimum for the upper edge is met.

These design requirements are illustrated in Figure 0.23**.**

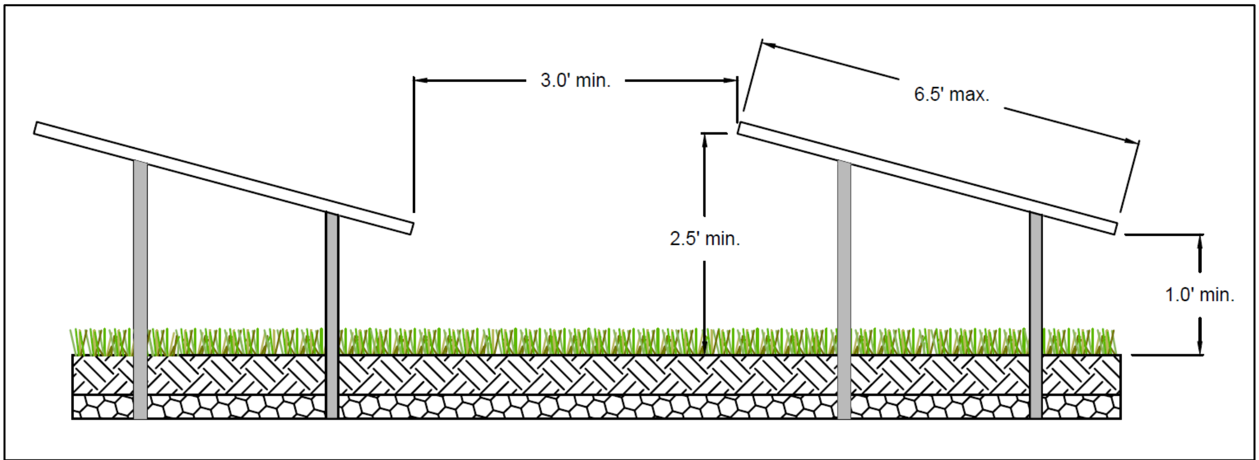

Figure 0.23 Design Requirements for structures constructed above green roofs.

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, if present (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). Verification shall be provided by an ASTM-certified lab using the methods described by ASTM tests E2396, E2397, E2398, or E2399, as appropriate. The test performed must be representative of the actual thickness/depth of each component of the green roof (i.e., a test performed on a 4-inch thick green roof media cannot be used to represent the maximum water retention value for an 8-inch thick green roof media). In the absence of laboratory test results, the baseline default values must be used. Equation 0.13 below shall be used to determine the storage volume retained by a green roof.

Equation 0.13 Storage Volume for Green Roofs

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

where:

Sv	=	green roof 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 0.10 as a baseline default in the absence of verification data)
DL	=	drainage layer depth (in.) (if the drainage layer is combined with the media layer, then this value is 0)

η_2 = verified drainage layer maximum water retention (use 0.0 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 - 50-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.

4.4.5 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 can South Lowcountry region be found in Table 0.24 below.

Table 0.24 Ground Covers Appropriate for Green Roofs in the State of South Carolina

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

Plant	Light	Moisture Requirement	Notes

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.
- Plants can be established using cuttings, plugs, mats, and, more rarely, 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). To achieve 50% coverage after 1 year and 80% coverage after 2 years, the recommended minimum spacing for succulent plantings is 2 plugs per square foot and 10 pounds per 100 square feet.
- When planting cuttings, plugs, and mats, 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.
- When appropriate species are selected, most green roofs will not require supplemental irrigation, except for temporary irrigation during drought or initial establishment. The use of water-efficient designs and/or use of non-potable sources is strongly encouraged. Permanent irrigation of extensive roof designs is prohibited. For intensive roofs, permanent irrigation may be included. However, permanent irrigation can adversely impact the rainfall retention capacity of the green roof. For this reason, soil moisture monitors are a required part of the irrigation system for all irrigated green roofs, and the calculated retention value for green roofs with permanent irrigation must be reduced by 50%.

- 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 4.4.4 Green Roof Design Criteria).

4.4.6 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 electric field vector mapping (EVFM®) or flood testing to ensure the system is watertight. Where possible, EVFM® is strongly recommended over the flood test, but not all impermeable membranes and deck systems are compatible with this method. Problems have been noted with the use of EFVM on black ethylene propylene diene terpolymer (EPDM) and with aluminized protective coatings commonly used in conjunction with modified bituminous membranes. If EVFM® or other leak detection systems are not possible, a flood test should be performed instead. The flood test is done by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system.
- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric) 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 (2015). 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 2 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% coverage after 1 year and 80% coverage after 2 years for plugs and cuttings, and 90% coverage after 1 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.

Construction phase inspection checklist for green roof practices can be found in Appendix E Construction Inspection Checklists.

4.4.7 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 0.25). 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, 2015)).

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.

Maintenance inspection checklist for green roofs and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

Table 0.25 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 and tree seedlings (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 the *<local jurisdiction>* 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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 local, state, and federal law.

4.4.8 Green Roof Stormwater Compliance Calculations

Unirrigated green roofs receive 100% retention value for the storage volume (Sv) provided by the practice. Permanently irrigated green roofs receive 50% retention value for the amount of Sv provided by the practice (see Table 0.26). Since the practice gets 100% retention value, it is not considered an accepted total suspended solids (TSS) treatment practice.

Table 0.26 Green Roof Design Performance

Retention Value (unirrigated)	$= Sv$

Retention Value (irrigated)	$= 0.5 \times Sv$
Accepted TSS Treatment Practice	N/A

The practice must be designed using the guidance detailed in Section 4.4.4 Green Roof Design Criteria.

Green roofs also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the storage volume (Sv) from the total runoff volume for the design storms. The resulting reduced runoff volumes can then be used to calculate a reduced Natural Resource Conservation Service (NRCS) curve number (CN) for the site or site drainage area (SDA). The reduced NRCS CN 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.

4.4.9 References

Atlanta Regional Commission (ARC). 2001. "Bioretention Areas." Georgia Stormwater Management Manual. Volume 2. Technical Handbook. Section 3.2.3. Atlanta Regional Commission. Atlanta, GA. Available Online: http://www.georgia stormwater.com/

ASTM E2396 / E2396M-15, Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Vegetative (Green) Roof Systems, ASTM International, West Conshohocken, PA, 2015, www.astm.org

ASTM E2397 / E2397M-15, Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems, ASTM International, West Conshohocken, PA, 2015, www.astm.org

ASTM E2398 / E2398M-15a, Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Vegetative (Green) Roof Systems, ASTM International, West Conshohocken, PA, 2015, www.astm.org

ASTM E2399 / E2399M-15, Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetative (Green) Roof Systems, ASTM International, West Conshohocken, PA, 2015, www.astm.org

ASTM E2400 / E2400M-06(2015)e1, Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems, ASTM International, West Conshohocken, PA, 2015, www.astm.org ASTM D3776 / D3776M-09a (2017), Standard Test Methods for Mass Per Unit Area (Weight) of Fabric, ASTM International, West Conshohocken, PA, 2017, www.astm.org

ASTM D4751-16, Standard Test Methods for Determining Apparent Opening Size of a Geotextile, ASTM International, West Conshohocken, PA, 2016, www.astm.org

ASTM D448-12 (2017), Standard Classification for Sizes of Aggregate for Road and Bridge Construction, ASTM International, West Conshohocken, PA, 2017, www.astm.org

Clark, S., B. Long, C. Siu, J. Spicher and K. Steele. 2008. "Early-life runoff quality: green versus traditional roofs." Low Impact Development 2008. Seattle, WA. American Society of Civil Engineers.

Dunnett, N. and N. Kingsbury. 2004. Planting Green Roofs and Living Walls. Timber Press. Portland, Oregon.

Green Roof Infrastructure: Plants and Growing Medium 401. Participant Manual. https://greenroofs.org/

Luckett, K. 2009. Green Roof Construction and Maintenance. McGraw-Hill Companies, Inc.

Northern Virginia Regional Commission (NVRC). 2007. Low Impact Development Manual. “Vegetated Roofs.” Fairfax, VA.

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

Weiler, S. and K. Scholz-Barth. 2009. Green Roof Systems: A Guide to the Planning, Design, and Construction of Landscapes over Structure. Wiley Press. New York, NY.

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

4.5 Rainwater Harvesting

<table>
<tr><th colspan="8">Rainwater Harvesting</th></tr>
<tr><td colspan="8">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.</td></tr>
<tr><th colspan="2">Site Applicability</th><th colspan="6">BMP Performance Summary</th></tr>
<tr><th>Land Uses</th><th>Required Footprint</th><th colspan="6">WQ Improvement: Moderate to High</th></tr>
<tr><td rowspan="3">▪ Urban
▪ Suburban
▪ Rural</td><td rowspan="3">Small</td><th colspan="2">TSS[1]</th><th colspan="2">Total N[1]</th><th colspan="2">Bacteria[1]</th></tr>
<tr><td colspan="2">Varies*</td><td colspan="2">Varies*</td><td colspan="2">Varies*</td></tr>
<tr><th colspan="6">Runoff Reductions</th></tr>
<tr><th>Construction Costs</th><th>Maintenance Burden</th><th colspan="3">Rate</th><th colspan="3">Volume</th></tr>
<tr><td>Low to Moderate</td><td>Moderate</td><td colspan="3">Moderate</td><td colspan="3">Varies*</td></tr>
<tr><th colspan="2">Maintenance Frequency:</th><th colspan="6">SWRv</th></tr>
<tr><th>Routine</th><th>Non-Routine</th><td colspan="6" rowspan="2">Refer to Rainwater Harvesting Calculator</td></tr>
<tr><td>Quarterly</td><td>Every 3 years</td></tr>
<tr><th colspan="2">Advantages/Benefits</th><th colspan="6">Disadvantages/Limitation</th></tr>
<tr><td colspan="2">▪ Reduces runoff rates and volume
▪ Can provide for/supplement irrigation needs</td><td colspan="6">▪ Stored water must be used on regular basis to maintain capacity
▪ Stagnant water can breed mosquitos</td></tr>
<tr><th colspan="2">Components</th><th colspan="6">Design considerations</th></tr>
<tr><td colspan="2">▪ Pretreatment
▪ Conveyance
▪ First flush diverter
▪ Cistern (storage tank)
▪ Overflow
▪ Low water cutoff</td><td colspan="6">▪ Plumbing codes (for indoor tanks)
▪ Size based on CDA, local rainfall patterns, and projected harvest rainwater demand
▪ Location and elevation of cistern
▪ Tank manufacturer's specifications</td></tr>
<tr><th colspan="8">Maintenance Activities</th></tr>
<tr><td colspan="2">▪ Inspect/clean pretreatment devices and first flush diverts
▪ Clear gutter/downspouts</td><td colspan="6">▪ Inspect and clean storage tank
▪ Maintenance log required</td></tr>
</table>

[1]*expected annual pollutant load removal*

**varies according to rainwater harvesting storage capacity and demand*

Rainwater harvesting systems store rainfall for future, non-potable water uses and on-site stormwater disposal/infiltration. 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. in- creased water conservation, water supply during drought and mandatory municipal water supply restrictions, decreased demand on municipal or groundwater supply, decreased water costs for the end-user, potential for increased groundwater recharge, supply of water post storm/hurricane in case of failed municipal infrastructure etc.).

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 (see Figure 0.24). Residential cisterns are commonly called rain barrels.

Figure 0.24 Example Cistern Application
Photo: Marty Morganello

The design includes the following:

R-1 Rainwater harvesting for non-potable uses

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 (e.g., 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, and
- Laundry.

The seven primary components of a rainwater harvesting system are discussed in detail in Section 4.5.4 Rainwater Harvesting Design Criteria. Some are depicted in Figure 0.25. The components include the following:

- CDA surface,
- Collection and conveyance system (e.g., gutter and downspouts) (number 1 in Figure 0.25)
- Pretreatment, including prescreening and first flush diverters (number 2 in Figure 0.25)
- Cistern (no number, but depicted in Figure 0.25)
- Water quality treatment (as required by Appendix J Rainwater Harvesting Treatment and Management Requirements)
- Distribution system
- Overflow, filter path, or secondary stormwater retention practice (number 8 in Figure 0.25)

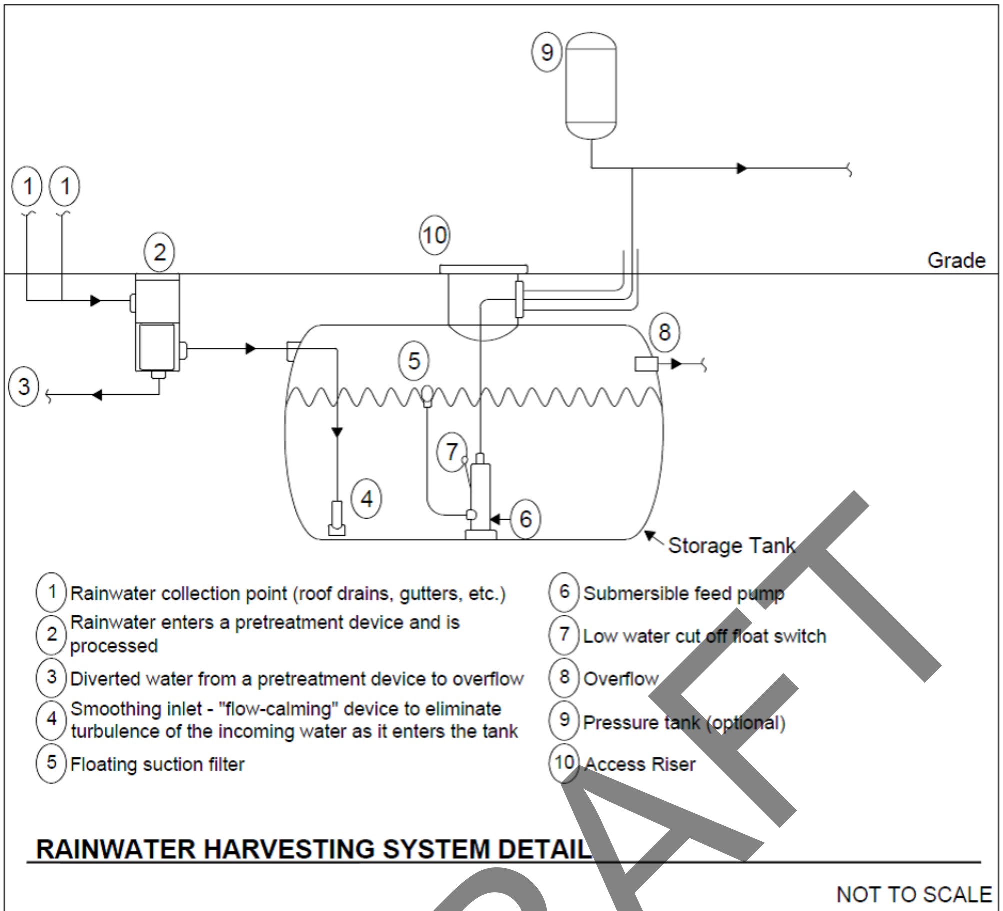

Figure 0.25 Example of a rainwater harvesting system detail.

4.5.1 Rainwater Harvesting Feasibility Criteria

Several 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. Designers and plan reviewers should consult with local construction codes to determine the allowable indoor uses and required treatment for harvested rainwater. This specification does not address indoor plumbing or disinfection issues. Designers and plan reviewers should refer to the 2012 Uniform Plumbing Code - Chapter 17 Non-potable Rainwater Catchment Systems, or local plumbing codes, as applicable.

Mechanical, Electrical, Plumbing. For systems that call for indoor use of harvested rainwater, the seal of a mechanical, electrical, and plumbing engineer is required.

Water Use. When rainwater harvesting will be used, the requirements in Appendix J Rainwater Harvesting Treatment and Management Requirements must be followed. This will outline the design assumptions 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 every inlet and outlet invert elevation 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, 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 SDA, 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 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 does 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 CDA to the cistern is the 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).

Contributing Drainage Area Material. The quality of the harvested rainwater will vary according to the roof material or CDA 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 to the NSF International NSF Protocol P151 standard.

Water Quality of Rainwater. Designers should also note that the pH of rainfall in the State 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.

Pollutant Hotspot Land Uses. Harvesting rainwater can be an effective method to prevent contamination of rooftop runoff that would result from mixing it with ground-level runoff from a stormwater hotspot operation. In areas where higher pollution loading is likely, rainwater harvesting should be avoided.

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 10 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.

Feasibility. Rainwater harvesting systems are very well suited to the warm environment of South Carolina and may help to relieve some of the pressure on drinking water aquifers, if applied on a wide scale. In areas with a high-water table, above ground installations will often be more appropriate.

Economic Considerations. Rainwater harvesting systems can provide cost savings by replacing or augmenting municipal water supply needs.

4.5.2 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.

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

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. The overflow pipe(s) must have a capacity greater than or equal to 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 and must include a backflow preventer if it connects directly to the combined sewer or storm sewer. All overflow from the system must be directed to an acceptable flow path that will not cause erosion during a 2-year storm event.

4.5.3 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.

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 per 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 - 50-year storm intensities must be used for the design of the conveyance and pretreatment portion of the system. The Rainwater Harvesting Storage Volume Calculator, discussed more in Section 4.5.4 Rainwater Harvesting Design Criteria, allows for input of variable filter efficiency rates for the design storm. To meet the requirements to manage the 2 - 50-year storms, a minimum filter efficiency of 90% must be met.

- **First Flush Diverters.** First flush diverters (see Figure 0.26) direct the initial pulse of rainfall away from the cistern. 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

the cisterns. 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 0.27). 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.

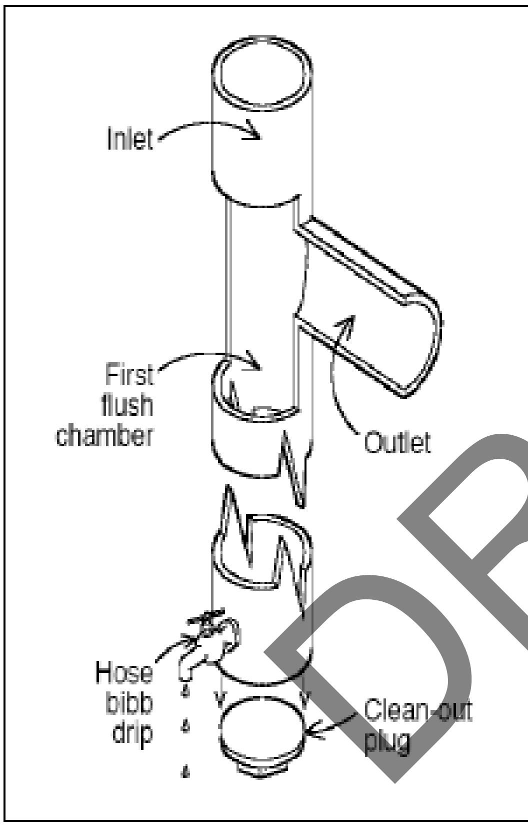

Figure 0.26 Diagram of a first flush diverter.
Texas Water Development Board, 2005

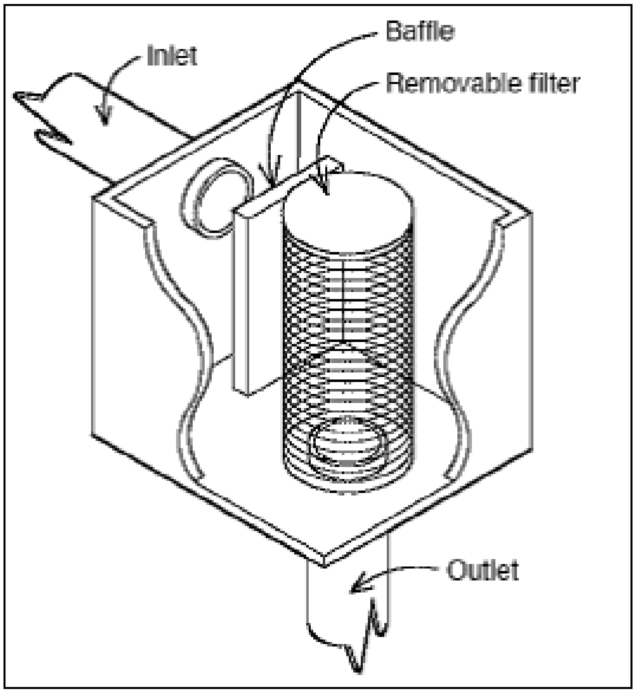

Figure 0.27 Diagram of a roof washer.
Texas Water Development Board, 2005

4.5.4 Rainwater Harvesting Design Criteria

System Components: Seven primary components of a rainwater harvesting system require special considerations (some of these are depicted in Figure 0.25):

- CDA or CDA surface
- Collection and conveyance system (i.e., gutter and downspouts)
- Cisterns (Storage Tank)
- Pretreatment, including prescreening and first flush diverters
- Water quality treatment (as described in Appendix J Rainwater Harvesting Treatment and Management Requirements)
- Distribution systems
- Overflow, filter path, or secondary stormwater retention practice

The system components are discussed below:

- **CDA Surface.** When considering CDA surfaces, 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.

  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 use.

- **Collection and Conveyance System.** See Section 4.5.4 Rainwater Harvesting Conveyance Criteria.

- **Pretreatment.** See Section 4.5.4 Rainwater Harvesting Pretreatment Criteria.
- **Cisterns (Storage Tank).** Also known as the storage tank, 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 0.27 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 0.27 Advantages and Disadvantages of Typical Cistern Materials

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 (20–50 gallons); limited application
Galvanized Steel	Commercially available, alterable, and moveable; available in a range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; must be lined for potable use; can only install above ground; soil pH may limit underground applications
Steel Drums	Commercially available, alterable, and moveable	Small storage capacity; prone to corrosion, and rust can lead to leaching of metals; verify prior to reuse for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast-in-Place Concrete	Durable, immoveable, 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

Source: Cabell Brand Center, 2007; Cabell Brand Center, 2009

- **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. Treatment requirements are described in Appendix J Rainwater Harvesting Treatment and Management Requirements.
- **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 4.5.2 Rainwater Harvesting Conveyance Criteria.

Rainwater Harvesting Material Specifications. The basic material specifications for rainwater harvesting systems are presented in Table 0.28. 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 0.28 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. ▪ 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 0.28) maximizes the available storage volume 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 - 50-year storm volumes with this cistern configuration, but the primary purpose is to address the smaller SWRv design storm.

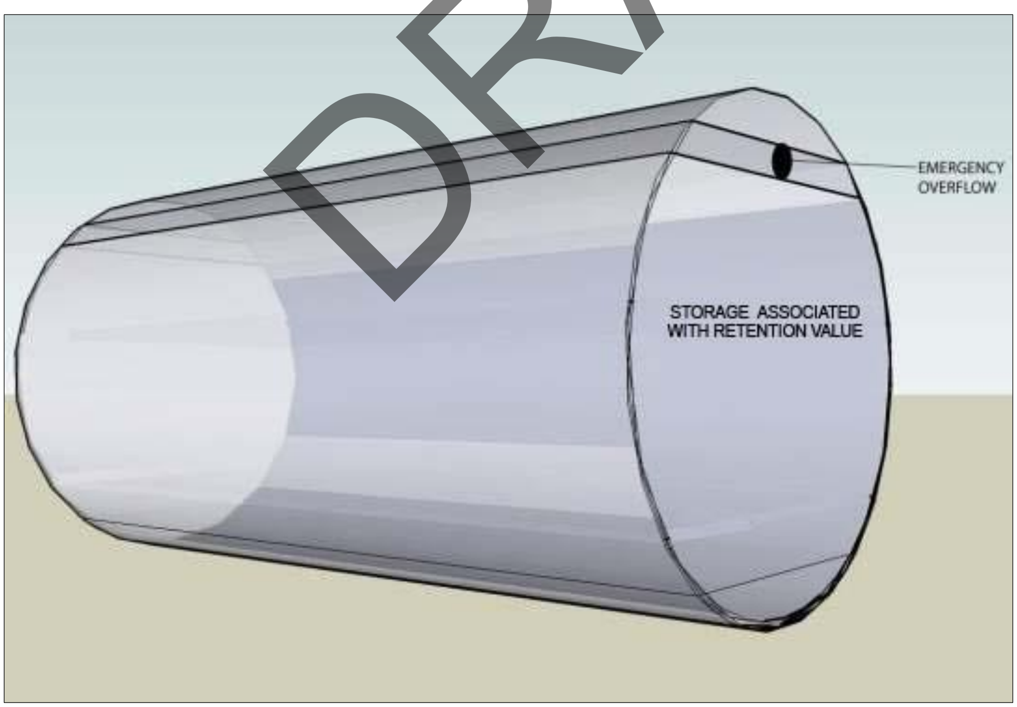

Figure 0.28 Cistern Design 1: Storage associated with the design storm volume only.

- **Cistern Design 2.** The second cistern set-up (Figure 0.29) uses cistern storage to meet the SWRv retention objectives and also uses additional detention volume to meet some or all of the 2 - 50-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.

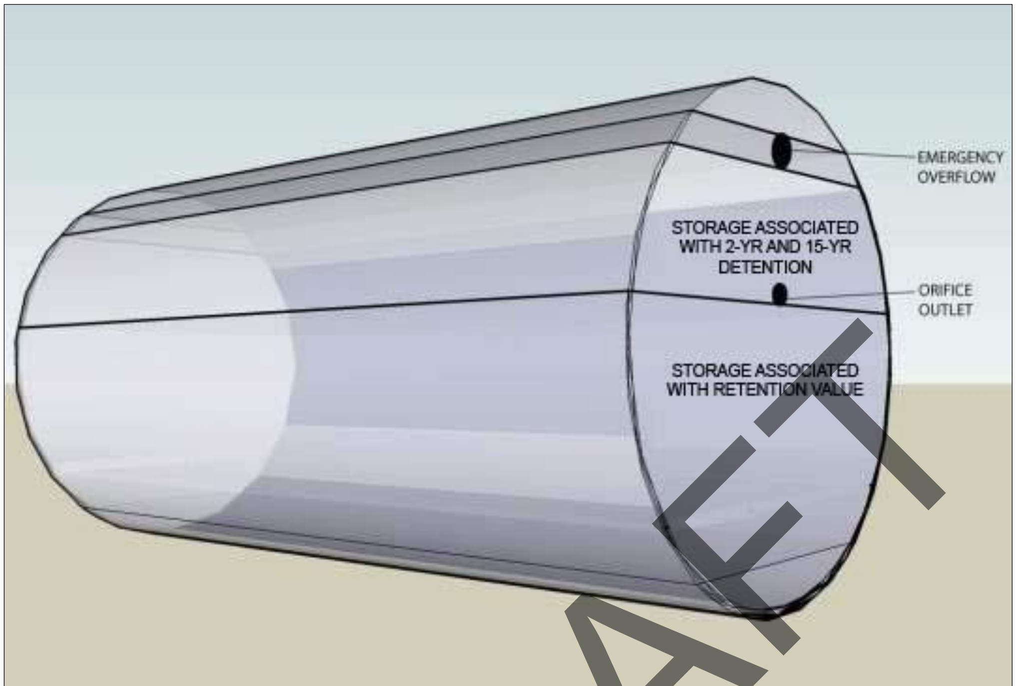

Figure 0.29 Cistern Design 2: Storage associated with design storm, channel protection, and flood volume.

- **Cistern Design 3.** The third cistern set-up (Figure 0.30) 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.
- While a small orifice is shown at the bottom of the cistern in Figure 0.30, 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.

  For this design, the secondary practice must be considered a component of the rainwater harvesting system with regard to the storage volume calculated in the General Retention Compliance Calculator in Appendix H. In other words, the storage volume associated with the secondary practice must not be included as a separate BMP because the secondary practice is an integral part of a rainwater harvesting system with a constant drawdown.

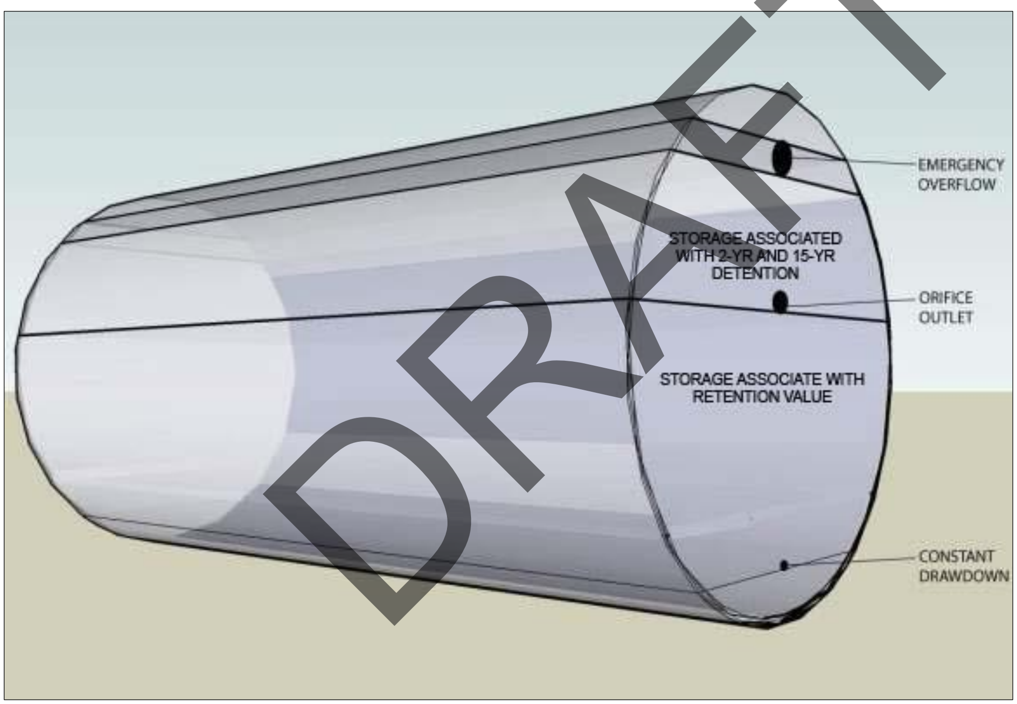

Figure 0.30 Cistern Design 3: Constant drawdown version where storage is associated with design storm, channel protection, and flood volume.

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 (Forasté 2011). The Rainwater Harvesting Storage Volume Calculator is for cistern sizing guidance and to quantify the retention value for storage volume achieved. This storage volume value is required for input into the General Retention Compliance Calculator and is part of the submission of a 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 Storage Volume Calculator can be found later in this section. The spreadsheet can be found on the District of Columbia website at https://doee.dc.gov/guidebook .

Rainwater Harvesting Storage Volume Calculator. The design specification provided in this section is linked with the Rainwater Harvesting Storage Volume 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. 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 - 50-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 0.31 for a graphical representation of these various incremental design volumes.

The design specification described in this section does not provide guidance for sizing larger storms, but rather provides guidance on sizing for the 85th and 95th percentile design storms.

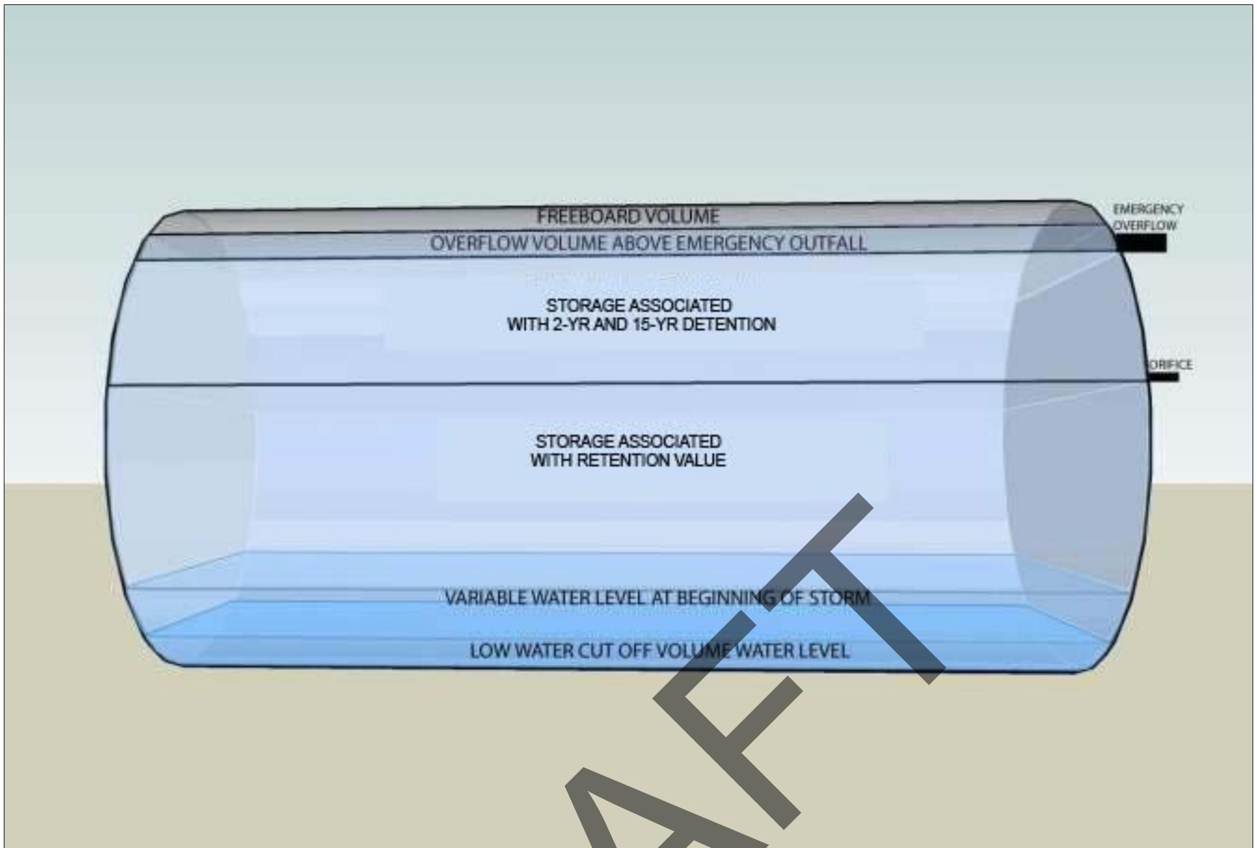

Figure 0.31 Incremental design volumes associated with cistern sizing.

The "Storage Associated with the Retention Value" is the average storage within the cistern that is modeled and available to retain rainfall. While the SWRv will remain the same for a specific CDA, the "Storage Associated with the Retention Value" is dependent on demand and storage volume retention objectives. It is the available space in the cistern between the average level at the beginning of a storm and the orifice outflow.

Water Contribution

- **Precipitation.** The volume of water contributing to the rainwater harvesting system is a function of the rainfall and CDA, 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 Storage Volume Calculator.

Water Losses

- **Contributing Drainage Area Runoff Coefficient.** The CDA is assumed to convey 95% of the rainfall that lands on its surface (i.e., $Rv = 0.95$).
- **First Flush Diversion.** The first 0.02 to 0.06 inches of rainfall 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 design storm will be captured successfully. For the 85th or 95th percentile storms, a minimum of 95% of the runoff should be conveyed into the cistern. The minimum values are included as the filter efficiencies in the Rainwater Harvesting Storage Volume Calculator, although they can be altered (increased) if appropriate. The Rainwater Harvesting Storage Volume 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 when the design storm is the SWRv. The appropriate rainfall intensity values for the 2 - 50-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.

Storage Volume Results. The Rainwater Harvesting Storage Volume Calculator determines the average daily volume of water in the cistern for a range of cistern sizes. From this value, the available storage volume for the 85th and 95th percentile storm can be calculated; it is simply the difference between the cistern size and the average daily volume. The available storage volume for the selected cistern size should be used as an input to the General Retention Compliance Calculator.

- **Available Storage Volume (Sv).** The volume available for storage of the 85th and 95th percentile storm 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 expensive. The curve helps the user to choose the appropriate cistern size, based on the design objectives and site needs.
- **Overflow Volume.** The volume of the overflows resulting from a 85th and 95th percentile precipitation event is also reported in this sheet. The overflow volume is also plotted to illustrate the effects of cistern size on overflow volume. An example chart is shown in Figure 0.32. The effect of diminishing returns is clear. Beyond a cistern size of 3,000 gallons, the overflow volume drops to zero. So, while the available storage continues to increase, the 85th and 95th percentile storm is entirely retained, and no additional retention value will be possible.

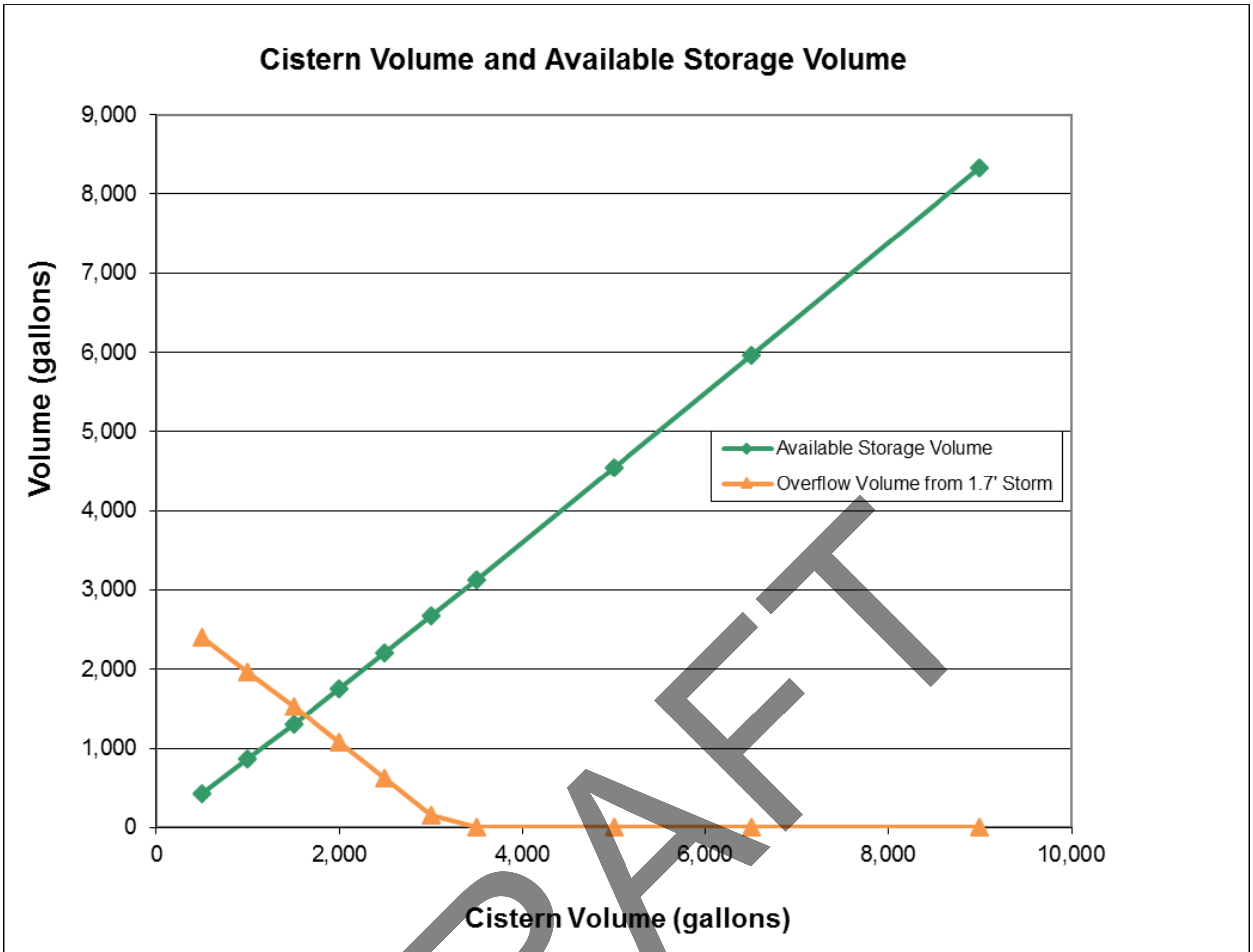

Figure 0.32 Example of retention value percentage achieved versus storage for non-potable uses.

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

- **Contributing Drainage Area.** Enter the CDA that was used in the Rainwater Harvesting Storage Volume Calculator into the Impervious Cover Draining to BMP column (cell D25).
- **Available Storage Volume.** Once a cistern has been selected, enter the Available Storage Volume (ft^3) associated with that cistern into the General Retention Compliance Calculator column called "Storage Volume Provided by BMP" in the "Rainwater Harvesting" row (cell O25). The storage volume is also needed for BMPs forms, and BMP Retention and Treatment Achieved section.

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 Storage Volume Calculator's modeled volume.

- **Cistern Storage Associated with Design Volume (Included).** This is the cistern design volume from the Rainwater Harvesting Storage Volume 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 - 50-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% 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.

4.5.5 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 during the months of May through October only. Justification must be provided if larger volumes are to be used.

4.5.6 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 in the mechanical, electrical, or plumbing fields 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
- System commissioning

Construction phase inspection checklist for rainwater harvesting practices and the Stormwater Facility Leak Test form can be found in Appendix E Construction Inspection Checklists.

4.5.7 Rainwater Harvesting Maintenance Criteria

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

Maintenance inspection checklists for rainwater harvesting systems and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

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 0.29 describes routine maintenance tasks necessary to keep rainwater harvesting systems in working condition. It is recommended that maintenance tasks 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 0.29 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 Appendix J Rainwater Harvesting Treatment and Management Requirements	Field verification and data logs must be available at all times and semiannual reports must be uploaded to the SW database annually.

Responsible Person	Frequency	Activity
	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.

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 the *<local jurisdiction>* 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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 local, state, and federal law.

4.5.8 Rainwater Harvesting: Stormwater Compliance Calculations

Rainwater harvesting practices receive a partial retention value for the SWRv, which is determined by using the Rainwater Harvesting Storage Volume Calculator, as described in Section 3.3.4 Rainwater Harvesting Design Criteria. Rainwater harvesting is not an accepted total suspended solids treatment practice.

Rainwater harvesting practices 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 through the 100-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN 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.

4.5.9 References

Atlanta Regional Commission (ARC). 2001. Georgia Stormwater Management Manual. Volume 2. Technical Handbook. Section 3.2.5. Atlanta Regional Commission. Atlanta, GA. Available Online at http://www.georgiastormwater.com/

Cabell Brand Center. 2007. Virginia Rainwater Harvesting Manual. Salem, VA. http://www.cabellbrandcenter.org

Cabell Brand Center. 2009. Virginia Rainwater Harvesting Manual, Version 2.0. Salem, VA. http://www.cabellbrandcenter.org/publications

Forasté, J. Alex. 2011. District of Columbia Cistern Design Spreadsheet. Center for Watershed Protection, Inc.

International Association of Plumbing and Mechanical Officials (IAPMO). 2012. Uniform Plumbing Code. IAPMO: Ontario, CA. Available at http://www.iapmo.org

National Atmospheric Deposition Program/National Trends Network. 2011 Data http://nadp.isws.illinois.edu

National Sanitation Foundation. 2014. Protocol P151, "Health Effects from Rainwater Catchment System Components. Available at http://info.nsf.org/Certified/Protocols/Listings.asp?TradeName=&Standard=P151

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.

NSF International. NSF P151: Certification of Rainwater Catchment System Components. https://www.nsf.org/newsroom_pdf/water_rainwater_catchment.pdf

Sharvelle, S.; Ashbolt, N.; Clerico, E.; Hultquist, R.; Leverenz, H.; and Olivieri, A. (2017). Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems. Prepared by the National Water Research Institute for the Water Environment & Reuse Foundation. Alexandria, VAWE&RF Project NoSIWM10C15.

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

4.6 Impervious Surface Disconnection

<table>
<tr><th colspan="8">Impervious Surface Disconnection</th></tr>
<tr><td colspan="8">Definition: This strategy involves managing runoff close to its source by directing it from rooftops and other impervious surfaces to pervious areas.</td></tr>
<tr><th colspan="4">Site Applicability</th><th colspan="4">BMP Performance Summary</th></tr>
<tr><th colspan="2">Land Uses</th><th colspan="2">Required Footprint</th><th colspan="4">WQ Improvement: Moderate to High</th></tr>
<tr><td colspan="2" rowspan="3">▪ Suburban
▪ Rural</td><td colspan="2" rowspan="3">Small</td><th>TSS[1]</th><th colspan="2">Total N[1]</th><th>Bacteria[1]</th></tr>
<tr><td>80%</td><td colspan="2">25%</td><td>N/A</td></tr>
<tr><th colspan="4">Runoff Reductions</th></tr>
<tr><th colspan="2">Construction Costs</th><th colspan="2">Maintenance Burden</th><th colspan="2">Rate</th><th colspan="2">Volume</th></tr>
<tr><td colspan="2">Low</td><td colspan="2">Low</td><td colspan="2">Moderate</td><td colspan="2">Low</td></tr>
<tr><th colspan="4">Maintenance Frequency:</th><th colspan="4">SWRv*</th></tr>
<tr><th colspan="2">Routine</th><th colspan="2">Non-Routine</th><th>D-1 (A/B)</th><th>D-1 (C/D)</th><th>D-2</th><th>D-3</th></tr>
<tr><td colspan="2">At least annually</td><td colspan="2">As needed</td><td>4 ft²</td><td>2 ft²</td><td>6 ft²</td><td>4 ft²</td></tr>
<tr><th colspan="4">Advantages/Benefits</th><th colspan="4">Disadvantages/Limitation</th></tr>
<tr><td colspan="4">▪ Low cost construction and maintenance
▪ Reduces runoff volume
▪ Helps restore pre-development hydrologic conditions</td><td colspan="4">▪ Only applicable to small drainage areas
▪ Most effective on A/B soils
▪ Difficult to apply to treatment trains
▪ Requires non-impervious receiving area</td></tr>
<tr><th colspan="4">Components</th><th colspan="4">Design considerations</th></tr>
<tr><td colspan="4">▪ Conveyance
▪ Receiving area
▪ Vegetation
▪ Receiving soils</td><td colspan="4">▪ Maximum CDA of 1,000 ft² per disconnection
▪ Disconnection area should be at least 15 feet long and 10 feet wide.
▪ Slope of receiving area should be < 2% (with turf reinforcement, <5%)
▪ Building setback for areas with < 1% slope</td></tr>
<tr><th colspan="8">Maintenance Activities</th></tr>
<tr><td colspan="4">▪ Typical lawn/landscaping maintenance</td><td colspan="4">▪ Ensure receiving area remains uncompacted and pervious</td></tr>
</table>

[1]*expected annual pollutant load removal*

**per 100 ft² of pervious receiving area*

In this practice, runoff from a rooftop or other small impervious surface is directed to a pervious surface or small practice to provide infiltration, filtering, or reuse (Figure 0.33**)**

Figure 0.33 Simple Rooftop Disconnection
Photo: Center for Watershed Protection

Definition. This strategy involves managing runoff close to its source by directing it from rooftops and other impervious surfaces to pervious areas. Disconnection practices can be used to reduce the volume of runoff that enters the combined or separate sewer systems. Applicable practices include the following:

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

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

4.6.1 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. Figure 0.34 illustrates some of these constraints. These and other feasibility criteria are described below and summarized in Table 0.30.

- **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%, or less than 5% 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 (HSG). The disconnection area must be kept well-vegetated with minimal bare spots—at least 95% soil cover.
- **Building Setbacks.** If the grade of the receiving area is less than 1%, downspouts must be extended 5 feet away from building.

Discharge Across Property Lines. Disconnection areas must be designed such that runoff is not directed across property lines toward other sites.

Economic Considerations. Disconnection is one of the least expensive BMPs available.

Table 0.30 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 HSG. 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%.

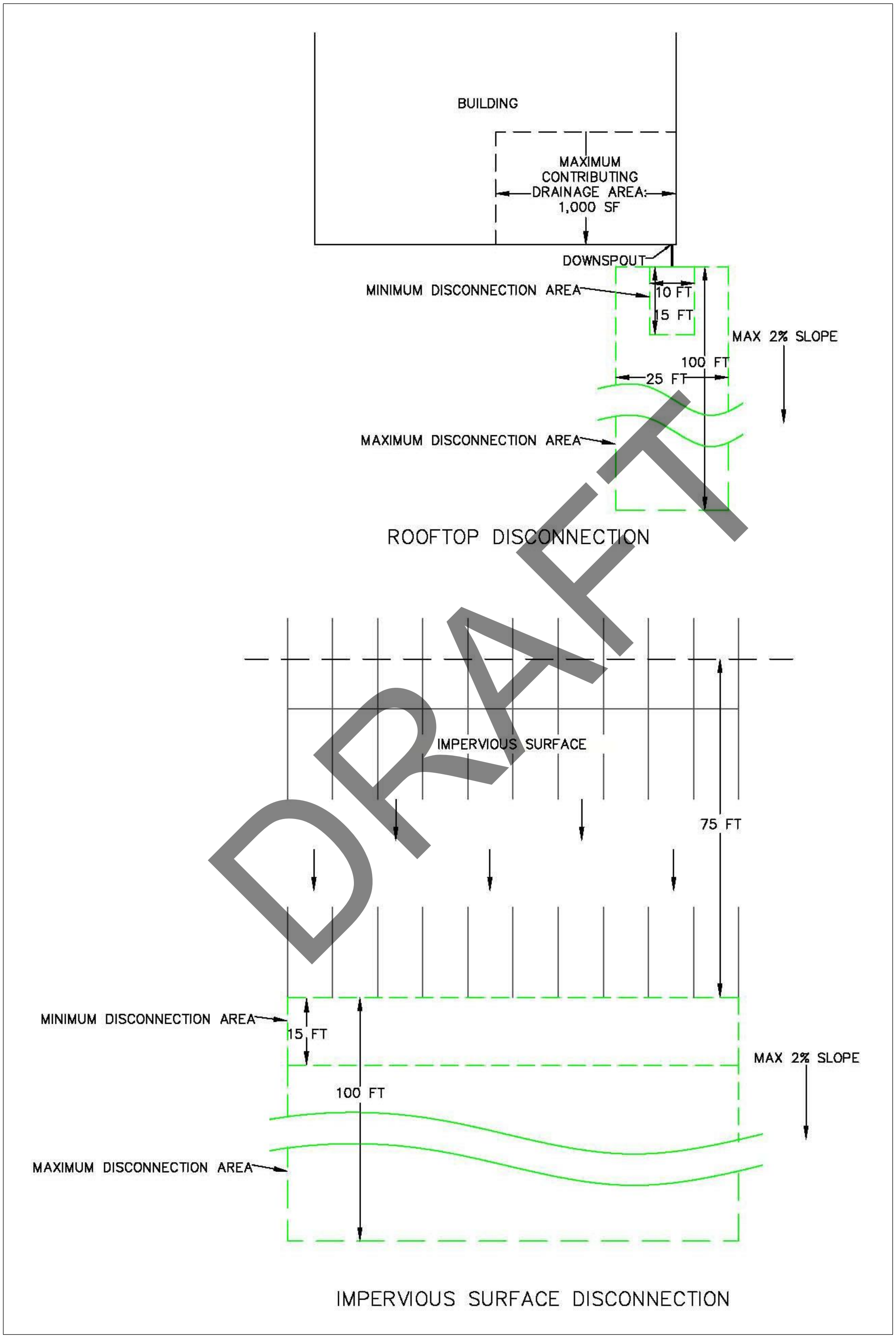

Figure 0.34 Design requirements for rooftop and impervious surfaces.

4.6.2 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 - 50-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.

4.6.3 Impervious Surface Disconnection Pretreatment Criteria

Pretreatment is not needed for simple impervious surface disconnection.

4.6.4 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 4.6.1 Impervious Surface Disconnection Feasibility Criteria.

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. If compaction occurs, soil amendments or post-construction aeration will be required (see Appendix C Soil Compost Amendment Requirements).

(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 4.6.1 Impervious Surface Disconnection Feasibility Criteria, with the following additions/exceptions:

- Minimum disconnection length is 40 feet.
- Disconnection area cannot include regulated wetlands and buffer areas.
- 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.

Level Spreaders. 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% 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% 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 C Soil Compost Amendment Requirements 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.

4.6.5 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 according to the Erosion and Sediment Control seeding and vegetation requirements. Designers must ensure that the maximum flow velocities do not exceed the acceptable values for the selected grass species and the specific site slope.

4.6.6 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 (establishment of 95% or greater groundcover).

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.

- No staging, parking, 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. Incidental utility construction includes protecting existing utilities, removing abandoned utilities, rearranging service lines, temporarily rearranging utilities, and adjusting utility appurtenances.
- Any conservation areas shall be protected by super silt fence, chain link fence, orange safety fence, or other measures to prevent sediment discharge consistent with soil erosion and sediment control standards and specifications.
- 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 CDA has been stabilized and perimeter soil erosion and sediment control measures have been removed and cleaned out. 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 significant rainfall event to look for evidence of gullies, outflanking, undercutting, or sparse vegetative cover. Spot repairs should be made as needed.

Construction phase inspection checklist for impervious cover disconnection can be found in Appendix E Construction Inspection Checklists.

4.6.7 Impervious Surface Disconnection Maintenance Criteria

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

Maintenance inspection checklists for disconnection can be found in Appendix F Maintenance Inspection Checklists.

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 the *<local jurisdiction>* 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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 local, state, and federal law.

4.6.8 Impervious Surface Disconnection Stormwater Compliance Calculations

Disconnection practices receive the following retention values:

D-1 (A/B) Simple disconnection to a pervious compacted cover area on HSG A or B soils: retention value of 4 cubic feet (30 gallons) per 100 square feet of receiving pervious area (compacted cover).

D-1 (C/D) Simple disconnection to a pervious compacted cover area on C or D Soils: retention value of 2 cubic feet (15 gallons) per 100 square feet 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 feet 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 feet of receiving pervious conservation area (soil amended).

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 as total suspended solids (TSS) treatment practices (see Table 0.31).

Table 0.31 Disconnection Retention Value and Pollutant Removal

Type of Simple Disconnection		Retention Value cubic feet (gallons) per 100 ft^2 of pervious receiving	Accepted TSS Treatment Practice
D-1 (A/B)	To a pervious compacted cover area (A/B	4 (30)	No
D-1 (C/D)	To a pervious compacted cover area (C/D	2 (15)	No
D-2	To a conserved natural cover area	6 (45)	No
D-3	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 - 50-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN 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.

4.6.9 References

Atlanta Regional Commission (ARC). 2001. "Bioretention Areas." Georgia Stormwater Management Manual. Volume 2. Technical Handbook. Section 3.2.3. Atlanta Regional Commission. Atlanta, GA. Available Online at http://www.georgiastormwater.com/

Charleston County. 2011. Charleston County Stabilization Specifications. Charleston County, South Carolina.

City of Roanoke Virginia. 2007. Stormwater Design Manual. Department of Planning and Building and Development. Available online at: http://www.roanokeva.gov/1065/Stormwater-Management-Code

Hathaway, J.M. and Hunt, W.F. 2006. Level Spreaders: Overview, Design, and Maintenance. Urban Waterways Design Series. North Carolina Cooperative Extension Service. Raleigh, NC. Available online: http://chesapeakestormwater.net/wp-content/uploads/downloads/2012/01/LevelSpreaders2006.pdf

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

Van Der Wiele, C.F. 2007. Level Spreader Design Guidelines. North Carolina Division of Water Quality. Raleigh, NC. Available online at http://h2o.enr.state.nc.us/su/documents/LevelSpreaderGuidance_Final_-3.pdf

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

4.7 Open Channel Systems

<table>
<tr><th colspan="8">Open Channel Systems</th></tr>
<tr><td colspan="8">Definition: Vegetated open channels that are designed to capture and treat or convey the design storm volume (SWRv).</td></tr>
<tr><th colspan="2">Site Applicability</th><th colspan="6">BMP Performance Summary</th></tr>
<tr><th>Land Uses</th><th>Required Footprint</th><th colspan="6">WQ Improvement: Moderate to High</th></tr>
<tr><td rowspan="3">▪ Suburban
▪ Rural</td><td rowspan="3">Moderate</td><td colspan="2">TSS[1]</td><td colspan="2">Total N[1]</td><td colspan="2">Bacteria[1]</td></tr>
<tr><td colspan="2">10-45%</td><td colspan="2">20-30%</td><td colspan="2">N/A</td></tr>
<tr><td colspan="6">Runoff Reductions</td></tr>
<tr><th>Construction Costs</th><th>Maintenance Burden</th><th colspan="3">Rate</th><th colspan="3">Volume</th></tr>
<tr><td>Low</td><td>Low</td><td colspan="3">Moderate</td><td colspan="3">Low</td></tr>
<tr><th colspan="2">Maintenance Frequency:</th><th colspan="6">SWRv*</th></tr>
<tr><td>Routine</td><td>Non-Routine</td><td>O-1a</td><td>O-1b</td><td>O-2</td><td>O-3</td><td>O-4</td><td>O-5</td></tr>
<tr><td>Quarterly</td><td>Every 10-15 years</td><td>10%</td><td>30%</td><td>60%</td><td>10%</td><td></td><td></td></tr>
<tr><th colspan="2">Advantages/Benefits</th><th colspan="6">Disadvantages/Limitation</th></tr>
<tr><td colspan="2">▪ Less expensive than curb and gutter
▪ Relatively low maintenance requirements
▪ Provides pretreatment if used as part of runoff conveyance system
▪ Provides partial infiltration of runoff in pervious soils
▪ Good for small drainage areas</td><td colspan="6">▪ Cannot alone achieve 80% removal of TSS;
▪ Must be carefully designed to achieve low flow rates in the channel (< 1.0 ft/s)
▪ May re-suspend sediment
▪ May not be acceptable for some areas because of standing water in channel</td></tr>
<tr><th colspan="2">Components</th><th colspan="6">Design considerations</th></tr>
<tr><td colspan="2">▪ Channel geometry
▪ Dense vegetation
▪ Check dams, as needed)</td><td colspan="6">▪ Maximum drainage area of 2.5 acres
▪ Slopes (<4% unless using O-4 or O-5)
▪ Runoff velocities must be non-erosive
▪ Depth to high water table at least 6 inches
▪ Vegetation must withstand both relatively high velocity flows and wet/dry periods.</td></tr>
<tr><th colspan="8">Maintenance Activities</th></tr>
<tr><td colspan="2">▪ Mow grass to 3 or 4 inches high
▪ Inspect for, and correct, formation of rills and gullies</td><td colspan="6">▪ Clean out sediment accumulation in channel
▪ Ensure that vegetation remains well established</td></tr>
</table>

[1]*expected annual pollutant load removal*

**Percent of Sv*

Often found along roadsides, parking lots, and along property boundaries, open channels can provide stormwater conveyance, capture and/or treatment (Figure 0.35**). One of the most visible stormwater BMPs, they are often part of stormwater conveyance systems.**

Figure 0.35 Example of an Open Channel
Photo: Center for Watershed Protection

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

O-1 Grass channels

O-2 Dry swales/bioswales

O-3 Wet swales

O-4 Two-stage ditch (may be used to provide detention for larger storm events)

O-5 Regenerative stormwater conveyance (RSC)

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 detention 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 (see Figure 0.38). 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 filter media. Their retention performance can be boosted when compost amendments are added to the bottom of the swale (see Appendix C Soil Compost Amendment Requirements). 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.

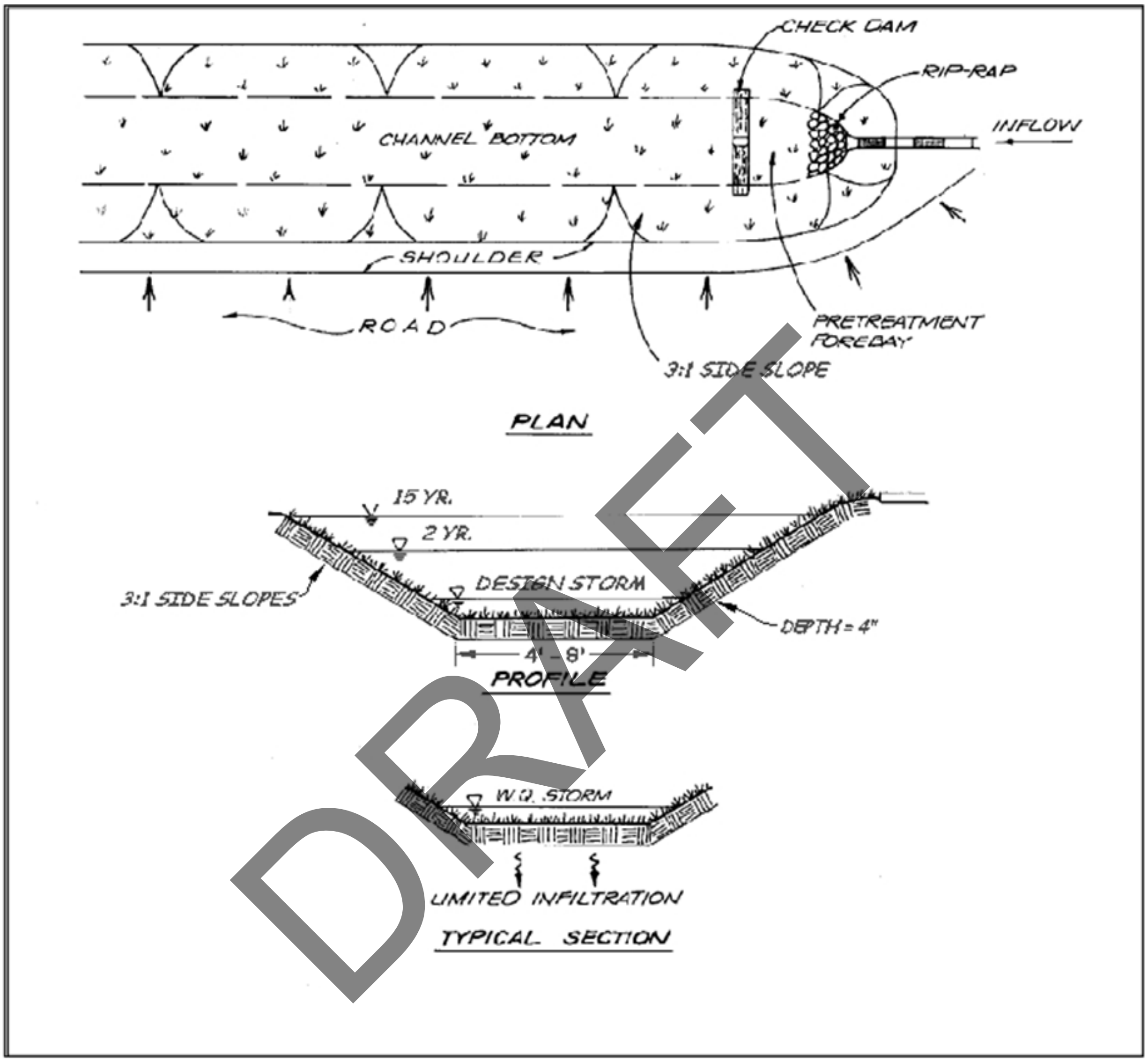

Figure 0.36 Grass channel typical plan, profile, and section views (O-1).

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; see Figure 0.39). 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 filter media below the channel that is identical to that used for bioretention. In most cases, the runoff treated by the filter 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. However, if soils are permeable, runoff infiltrates into underlying soils and the dry swale can be designed without an underdrain as if it were an enhanced bioretention. In either case, check dams should be constructed to encourage ponding (see Site Topography). 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.

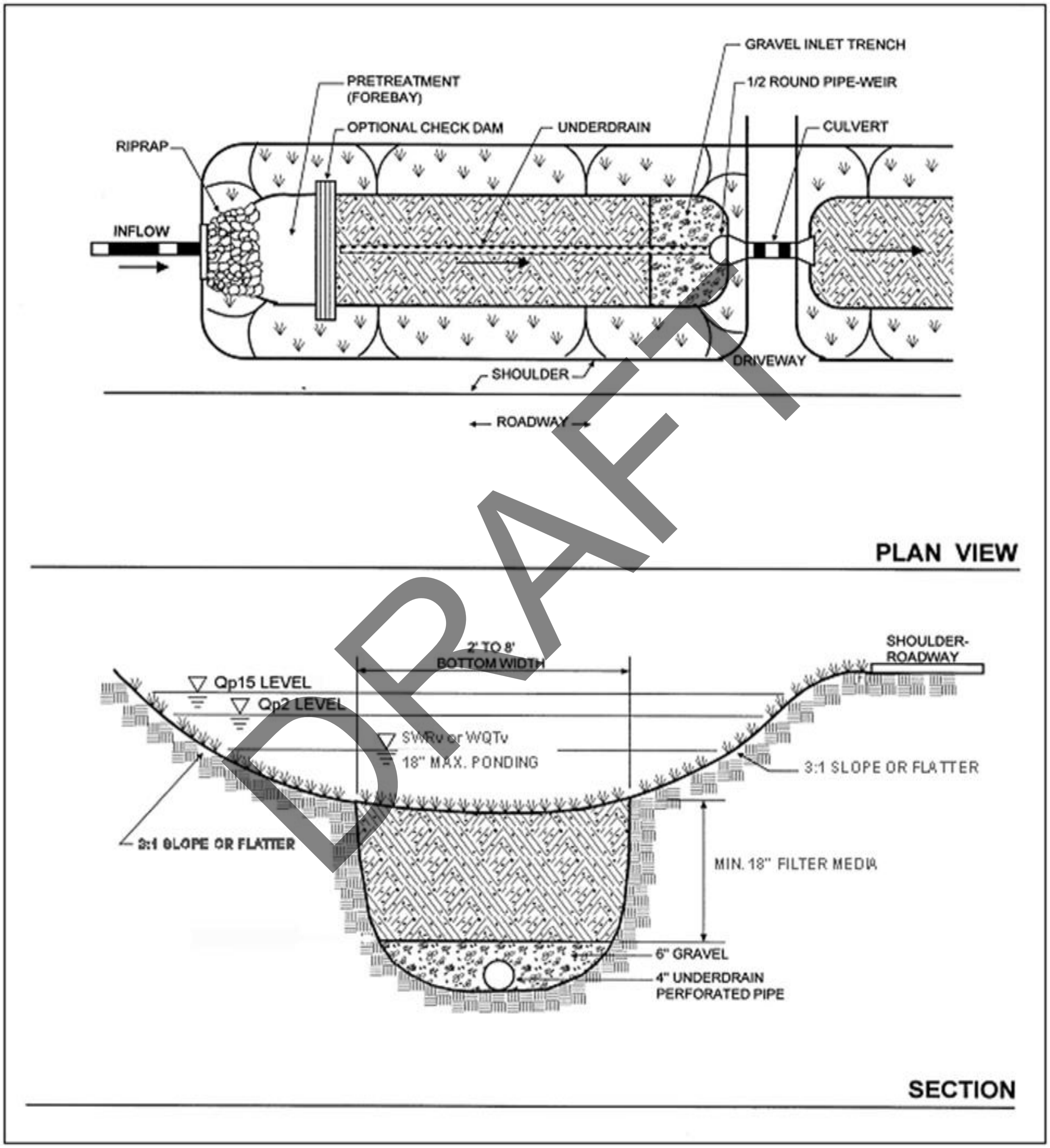

Figure 0.37 Example of a dry swale/bioswale (O-2).

Wet swales (O-3) can provide a modest amount of runoff filtering within the conveyance (see Figure 0.40). 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).

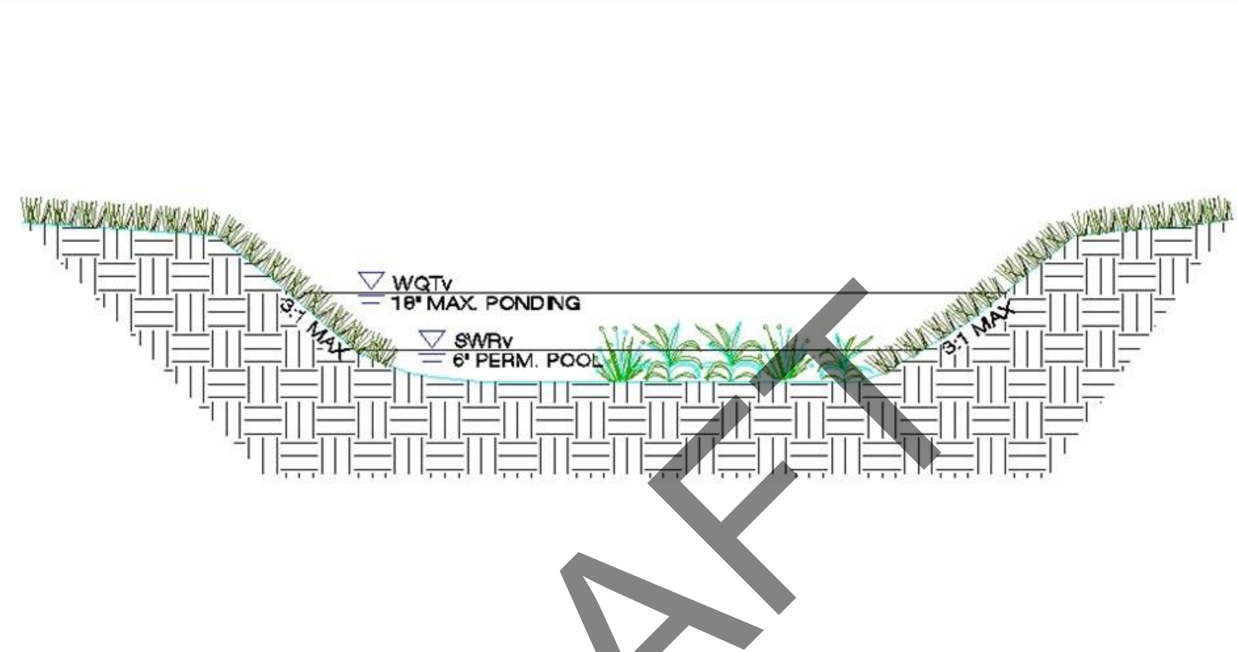

Figure 0.38 Example of a wet swale (O-3).

Two Stage Ditches (O-4). Show in Figure 0.39, two stage ditches are a modification of other open channel designs that provides some temporary detention for larger storm events. This option utilizes a modified cross section that includes a low flow conveyance channel to convey the "channel forming" (up to 2-year) event, and a bench with flattened side slopes to convey larger storm events. Originally used as an agricultural practice in the Midwestern United States, it mimics the geometry of a natural stream, thereby harnessing some aspects of natural fluvial functioning.

This design option has the potential to provide greater detention for larger storm events, minimizes scour during large storms, increases bank stability, and can enhance nitrogen removal by providing a greater reactive surface for nutrient cycling. However, it requires a wider width than a trapezoidal or parabolic channel, and consequently cannot be applied on sites with a very narrow right of way. Additional information and design criteria can be found in Chapter 10 - Part 654 Stream Restoration Design, National Engineering Handbook (USDA, 2007).

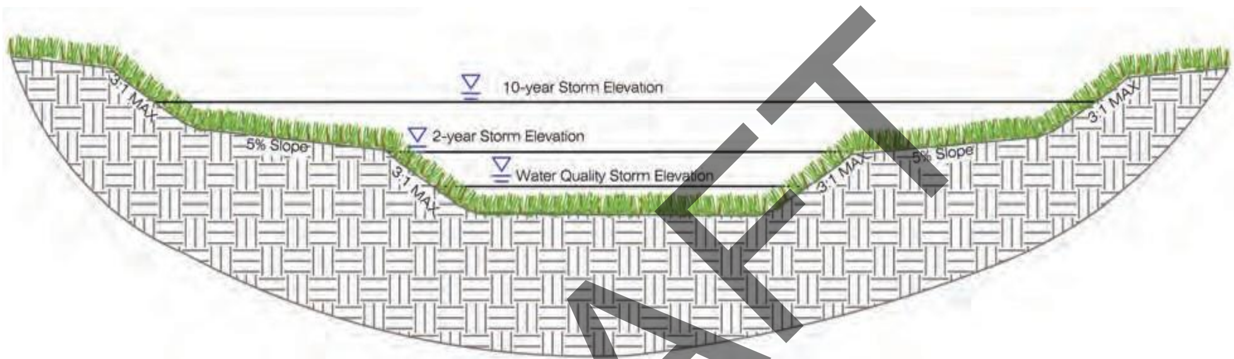

Figure 0.39 Example of Two Stage Ditches (O-4)

Regenerative Stormwater Conveyance (O-5). RSC is a unique conveyance practice that can be used in locations where other conveyance practices are infeasible, or as a restoration practice for eroded or degraded outfalls and drainage channels (Figure 0.40). RSC utilizes a series of shallow aquatic pools, riffle weir grade controls, native vegetation and underlying sand and woodchip beds to treat, detain, and convey storm flow. It can be used in places where grades make traditional stormwater practices difficult to implement. Because of the regional topography and waters of the state limitations, RSC Systems will have limited application in the Southern Lowcountry. RSC Systems combine features and treatment benefits of Swales, Infiltration, Filtering and Wetland practices. In addition, they are designed to convey flows associated with larger storm events in a non-erosive manner, which results in a reduction of channel erosion impacts commonly encountered at conventional stormwater outfalls and headwater stream channels.

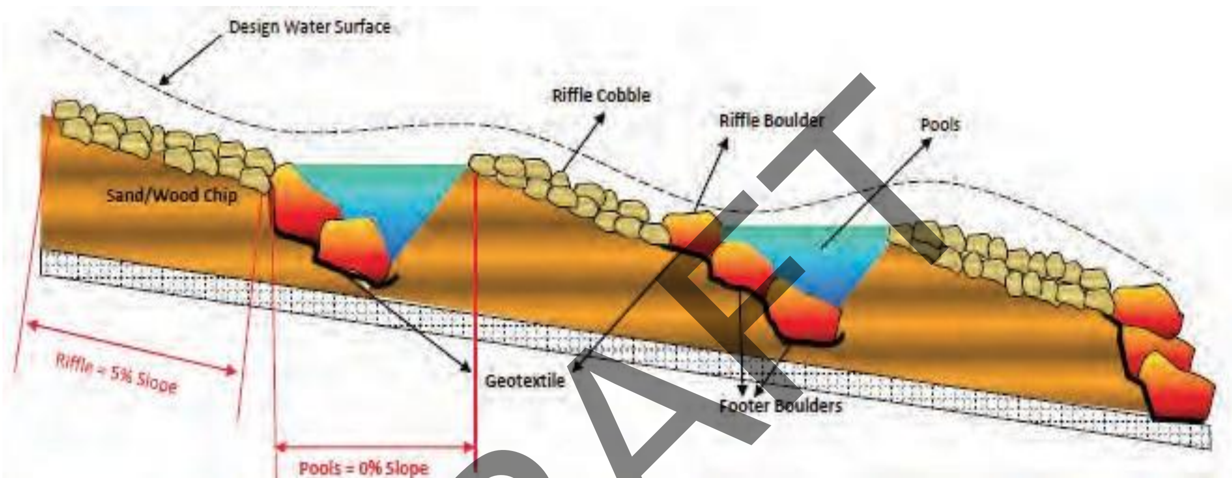

Figure 0.40 Example of Regenerative Stormwater Conveyance (O-5)

4.7.1 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 CDA to an open channel should be 2.5 acres, preferably less. When open channels treat and convey runoff from CDAs 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 4.7.4 Open Channel Design Criteria). Dry Swales should be approximately 3%–10% of the size of the CDA, depending on the amount of impervious cover. Wet swale footprints usually cover about 5%–15% of their CDA.

Available Space. Open channel footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. 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%. Check dams can be used to reduce the effective slope of the channel and lengthen the contact time to enhance filtering and/or infiltration. Longitudinal slopes of less than 2% are ideal and may eliminate the need for check dams. However, channels designed with longitudinal slopes of less than 1% should be monitored carefully during construction to ensure a continuous grade so as 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 CDA limitations and design criteria can be met:

- Within a roadway or bicycle path 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 parkland, sports fields, golf courses, and other turf-intensive land uses, or to treat CDAs with both impervious and managed turf cover (such as residential streets and yards).

Open channels are not recommended when residential density exceeds more than four (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 (unless an infiltration-based design will be used). 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 that must be designed with enough capacity to (1) convey runoff from the 25-year design storm at non-erosive velocities, and (2) contain the 25-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 25-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 0.5 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 low infiltration rates 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 B Geotechnical Information Requirements for Underground BMPs to eliminate the requirements for a dry swale underdrain.
- Grass channels situated on low-permeability soils may incorporate compost amendments to improve performance (see Appendix C Soil Compost Amendment Requirements).
- Wet swales work best on the more impermeable HSG C or D soils.
- At 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 PROW. 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 PROW 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, stormwater cannot flow from the open channel reservoir layer or via baseflow to the traditional pavement base layer, existing structure foundations, or future foundations which may be built on adjacent properties Open channels should be set back at least 10 feet down-gradient from building foundations and property lines, 50 feet from septic system fields and 150 feet from public or private drinking water wells. The 10-foot building setback may be relaxed if an impermeable building liner is installed.

Pollutant Hotspot Land Use. In areas where higher pollutant loading is likely (i.e. oils and greases from fueling stations or vehicle storage areas, sediment from un-stabilized pervious areas, or other pollutants from industrial processes), appropriate pretreatment, such as an oil- water separator or filtering device must be provided. These pretreatment facilities should be monitored and maintained frequently to avoid negative impacts to the channel and subsequent water bodies.

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.

On sites with existing contaminated soils, infiltration is not allowed; dry and wet swales on these hotspots must include an impermeable liner.

Feasibility. Open channels are ideally suited to the Southern Lowcountry environment, since open channel drainage is often the norm due to the flat topography. Depending on underlying soil and other characteristics, however, a specific open channel option may be the most appropriate. For example, the wet swale design option is most suited to areas with elevated groundwater tables, while dry swales and grassed channels are best suited for sandy soils of the coastal plain.

Economic Considerations. While most open channel designs provide relatively small water quality credits when compared with other stormwater practices, they nevertheless provide greater quality benefits than traditional conveyance designs, such as curb and gutter.

4.7.2 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 4.7.4 Open Channel Design Criteria.

Open channels must also convey the 25-year storm at non-erosive velocities (generally less than 6 feet per second) for the soil and vegetative cover provided. The final designed channel shall provide 6 inches 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.

RSC systems are typically designed to convey larger storm events, up to and including the 100- year storm event.

4.7.3 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 CDAs 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% 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% 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 5H:1V or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5% (20H:1V) cross slope and 3H:1V 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% 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.

4.7.4 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 CDA 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.
- In the two-stage ditch option, the benches above the elevation of the 2-year storm event should have between a 0% and 3% side slope. In addition, the width of each bench should, at a minimum, be equal to the top width of the lower conveyance channel.

- RSC has several specific geometry requirements, which are outlined in RSC Sizing below.

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 (25-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%, as indicated in Table 0.32.

Table 0.32 Typical Check Dam Spacing to Achieve Effective Channel Slope

Channel Longitudinal Slope (%)	Check Dam Spacing to Achieve Effective Slope [a, b, c]	
	Effective Slope of 2% (ft)	Effective Slope of 0%–1% (ft)
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 dissipator at the downstream toe.
[b] Check dams require weep holes at the channel invert. Swales with slopes less than 2% will require multiple weep holes (at least 3) in each check dam.
[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% 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 0.32.

Dry Swale Filter Media. Dry swales require replacement of native soils with a prepared filter media. The filter 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 4.1 Bioretention. The batch receipt confirming the source of the filter media must be submitted to the *<local jurisdiction>* inspector. One acceptable design adaptation is to use 100% sand for the first 18 inches of the filter and add a combination of topsoil and compost, as specified in Appendix C Soil Compost Amendment Requirements, 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 4.7.6 Open Channel Construction Sequence.

Dry Swale Underdrain. Some dry swale designs will not use an underdrain (where soil infiltration rates meet minimum standards). See Section 4.7.1 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 No. 8 or No. 89 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. The maximum depth of the underdrain stone layer combined with the choking layer is 12 inches, and it cannot extend beyond the surface dimensions of the dry swale filter media.

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 PVC geomembrane liner or an equivalent of an appropriate thickness (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 well-anchored, 4- to 6-inch diameter PVC pipe observation wells along the length of the swale. For a dry swale with an underdrain, the wells should be tied into any Ts or Ys in the underdrain system and must extend upward above the surface of the ponding. These observation wells may double as clean outs. For an infiltrating dry swale, the observation well should be perforated in the gravel layer only.

Grass Channel Material Specifications. The basic material specifications for grass channels are outlined in Table 0.33

Table 0.33 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-erodible 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.

Dry Swale Material Specifications. For additional material specifications pertaining to dry swales, designers should consult Section 4.1.4 Bioretention Design Criteria and Table 0.34.

Table 0.34 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.

Material	Specification	Notes
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 filter 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 (10 times) higher than the soil subgrade permeability. ▪ Apply along sides of the filter media only and do not apply along the swale bottom.	
Choking Layer	A 2- to 4-inch layer of choker stone (typically No. 8 or No. 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 and Cleanouts	4-inch or 6-inch rigid schedule 40 PVC pipe, with 3 or 4 rows of 3/8-inch perforations at 6 inches on center.	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.
Observation Wells	4-inch or 6-inch rigid schedule 40 PVC pipe	For dry swales with underdrains, tie the non-perforated observation well to the underdrain via T or Y connection. This observation well can double as a cleanout. For dry swales without an underdrain, the pipe should only be perforated in the gravel layer. The observation wells should extend to the top of ponding.
Impermeable Liner	Where appropriate, use a PVC geomembrane liner or equivalent.	
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.	

RSC Material Specifications. RSC has several design elements that are unique to this practice. The practice includes riffle and pool segments, underlain with a sand/ wood chip bed, and with a top dressing of compost and plant material. Table 0.35 outlines the materials needed for this practice.

Table 0.35 Regenerative Stormwater Conveyance System Material Specifications

Material	Specification
Footer Boulders	Should have a natural appearance and be equivalent in size to Class 3 Rip Rap (aver- age diameter 26.4 inches)
Cobble	Should have a natural appearance and a minimum diameter of 6”

Sand/ Woodchip Bed	The sand component of the sand/wood chip bed should meet the AASHTO- M-6 or ASTM-C-33, 0.02 inches to 0.04 inches in size. Sand shall be a silica-based coarse aggregate. Substitutions such as Diabase and Gray- stone (AASHTO) #10 are not acceptable. No calcium carbonate or dolomitic sand substitutions are acceptable. No "rock dust" can be used for sand. Locally-approved pulverized glass may be substituted if the local authority undertakes testing to verify compliance with the particle size specification. No art glass shall be used for a pulverized glass material. For woodchips, use aged, shredded hardwood chips/mulch. The woodchips should be added to the sand mix, approximately 20 percent by volume, to increase the organic content and promote plant growth and sustainability.
Choker Stone	The choker stone layer between the sand bed and the bank run gravel should be clean, washed #8 or #78 stone.
Bank Run Gravel	The bank run gravel layer that is placed beneath and above the sand bed/choker stone layers should be constructed using clean, washed # 5 or # 57 coarse aggregate.
Compost	The compost used as a top dressing over the RSC System should consist of a 100% organic compost, with a pH of between 6.0 and 7.0, a moisture content of between 30 and 55%, and a particle size of 0.25 inches or less. (See Appendix C for compost specifications)
Wood Chips	The wood chips used within the sand bed should consist of double-shredded or double-ground hardwood mulch that is free of dyes, chromated copper arsenate and other preservatives.
Plant Materials	Plants should be native species, appropriate to the planting/wetness zone where they are located.

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 C Soil Compost Amendment Requirements.
- The amended area will need to be rapidly stabilized with perennial, salt-tolerant grass species (if contributing impervious surfaces are likely to be salted).
- 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 - 50-year storms if an on-line application (Haan et. al, 1994).
- Peak flow rates for the 25-year frequency storm must be non-erosive, in accordance with Table 0.37 (see Section 0 Open Channel Landscaping Criteria), or subject to a site-specific analysis of the channel lining material and vegetation; and the 25-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 0.14 through Equation 0.18.

The bottom width of the grass channel is therefore sized to maintain the appropriate flow geometry as follows:

Equation 0.14 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 0.15 Continuity Equation

$$Q = V \times (W + 3 \times D) \times D$$

where:

Q	=	design storm peak flow rate (cfs)
V	=	design storm flow velocity (ft/s)
W	=	channel bottom width (ft)
D	=	flow depth (ft)

(Note: Channel width (W) plus 3 times the depth (D) represents the average width of a trapezoidal channel with 3H:1V side slopes. Average width multiplied by depth equals the cross-sectional flow area.)

Combining Equation 0.14 and Equation 0.15, and rewriting them provides a solution for the minimum width (Equation 0.16):

Equation 0.16 Minimum Width

$$W = \frac{n \times Q}{1.49 \times D^{5/3} \times S^{1/2}} - (3 \times D)$$

where:

W	=	channel bottom width (ft)
n	=	roughness coefficient (0.2, or as appropriate)
Q	=	design storm peak flow rate (cfs)
D	=	flow depth (ft)
S	=	channel slope (ft/ft)

Equation 0.17 provides the corresponding velocity:

Equation 0.17 Corresponding Velocity

$$V = \frac{Q}{(W + 3 \times D) \times D}$$

where:

V	=	design storm flow velocity (ft/s)
Q	=	design storm peak flow rate (cfs)
W	=	channel bottom width (ft)
D	=	flow depth (ft)

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 0.18 can then be used to ensure adequate hydraulic residence time.

Equation 0.18 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), as shown in Equation 0.19.

Equation 0.19 Grass Channel Storage Volume

$$Sv = DesignStorm$$

where:

Sv	=	total storage volume of grass channel (ft^3)
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, filter media, and gravel reservoir layers of the dry swale.

Total storage volume of the BMP is calculated using Equation 0.20.

Equation 0.20 Dry Swale Storage Volume

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

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, including mulch layer (ft)
η_{media}	=	effective porosity of the filter media (typically 0.25)
d_{gravel}	=	depth of the underdrain and underground storage gravel layer, including choker stone (ft)
η_{gravel}	=	effective porosity of the gravel layer (typically 0.4)
$SA_{average}$	=	average surface area of the dry swale (ft^2)

typically, where SA_{top} is the top surface area of dry swale,

$$SA_{average} = \frac{SA_{bottom} + SA_{top}}{2}$$

$d_{ponding}$ = the maximum ponding depth of the dry swale (ft)

Equation 0.20 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 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 0 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 - 50-year runoff volumes to satisfy stormwater quantity control requirements.

Note: 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 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 0.21). The total Sv cannot exceed the design SWRv.

Equation 0.21 Wet Swale Storage Volume

$$Sv = Pond\ permanent\ pool\ volume + 24\ hour\ ED\ volume$$

RSC Sizing. RSC design is an iterative process in which the channel is sized to convey the 100-year storm event, using manning's equation for parabolic channels as described in detail by Anne Arundel County, MD (2011). The following description provides an overview of this process, but designers should consult Anne Arundel County (2011) or the latest design variation for RSC for additional design guidelines. The Anne Arundel County guidance can be found at http://www.aacounty.org/DPW/Watershed/StepPoolStorm-Conveyance.cfm.

Some key RSC sizing considerations include the following:

- One control structure and pool (riffle-pool) combination is needed for each foot of elevation difference along the channel.
- The length of each grade control structure or pool is determined by

- Equation 0.22

Equation 0.22 Riffle Pool Length

$$L_{pool} = \frac{L_{riffle}}{(Elevation\ Change) \times 2}$$

where:

L_{pool}	=	surface length of each pool (ft)
L_{riffle}	=	total length of riffle pool (ft)
Elevation Change	=	difference in elevation between pool and bottom pool (ft)

- In areas with steep slopes (10% or greater) the length of the pool or riffle may be small (<10’). In these locations, cascades may be needed as a part of the system design.
- The minimum width of grade control structures should be 8 ft and the width should be equal to 10 times the channel depth (Figure 0.41).
- The depth of flow in the riffle sections should be less than 4 inches.
- Cobbles in the riffle section should be sized so that the velocity of the 100-year storm is non-erosive (Table 0.36).

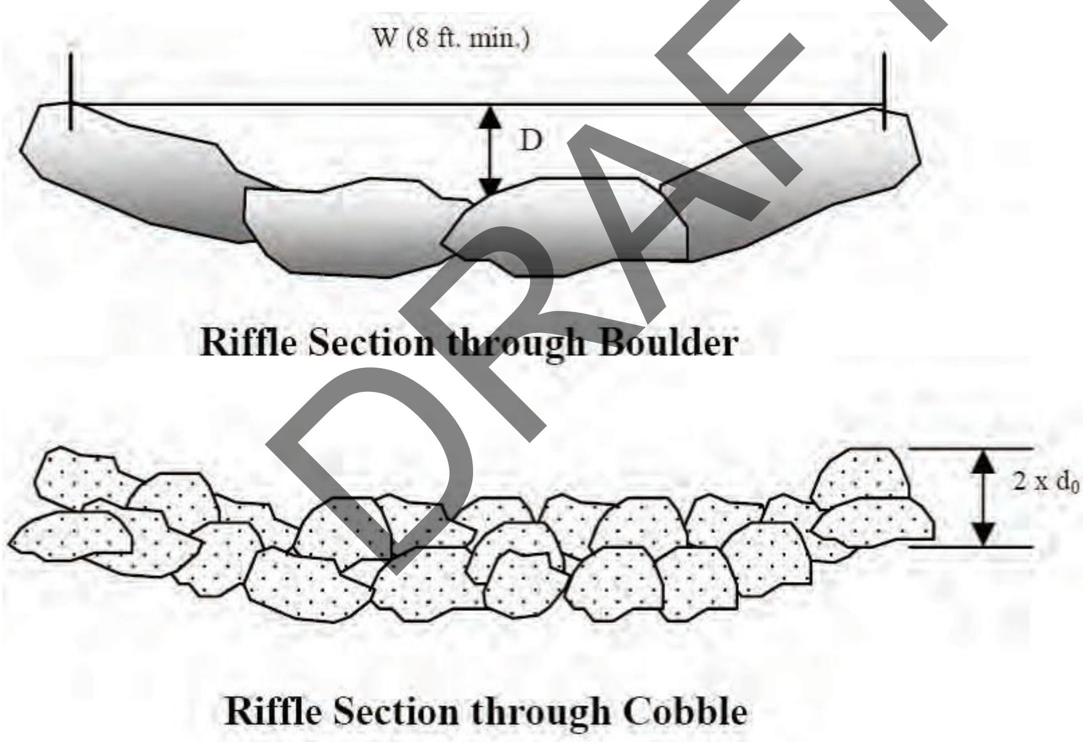

Figure 0.41 Typical Width and Depth of Riffle Sections
Source: Anne Arundel County, 2011

Table 0.36 Maximum Allowable Velocity

Cobble size (in)	Allowable velocity (ft/s)
4	5.8
5	6.4
6	6.9
7	7.4
8	7.9
9	8.4
10	8.8
11	9.2
12	9.6
15	10.4

- Pools should be between 1.5 and 3 feet deep, and equal to the width of the riffle sections.
- The RSC system is underlain with a sand bed with a 1.5 foot depth and a width between 4 and 14 feet.
- The downstream edge of the riffle should incorporate a series of boulders in a parabolic shape.
- Place a cobble apron below the riffle section to allow for a stable transition between the riffle section and the downstream pools when the pools are dry. The cobble apron should be approximately 5 feet wide and 3 feet long.

The total Sv in the RSC system (available for water quality treatment) is determined by Equation 0.25.

Equation 0.23 RSC Systems Storage Volume

$$Sv = V_{pool} + V_{sandbed}$$

where:

Sv = total storage volume of RSC system (ft^3)
V_{pool} = volume in pools (ft^3)
$V_{sandbed}$ = volume in sand bed (ft^3), use effective porosity of 0.25

4.7.5 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 0.37. 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. For more information on stabilization seeding, see the Charleston County Stabilization Specifications.

Table 0.37 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 0 Stormwater Wetlands.

If roadway salt will be applied to the CDA, 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% 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.

4.7.6 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 and 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 0 Stormwater Wetlands.

Step 1: **Protection During Site Construction.** Ideally, open channels should remain outside the limits 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 CDA 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. Add the perforated underdrain pipe. Add the remaining stone jacket, and then pack No. 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 filter 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 C Soil Compost Amendment Requirements.

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 the South Carolina BMP Handbook (SDHEC, 2005).

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.

Construction phase inspection checklist is available in Appendix E Construction Inspection Checklists.

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.

4.7.7 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 0.38 provides a schedule of typical maintenance activities required for open channels.

Table 0.38 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.

Schedule	Maintenance Activity
Quarterly	▪ Ensure that the CDA, inlets, and facility surface are clear of debris. ▪ Ensure that the CDA is stabilized. Perform spot-reseeding if where needed. ▪ Remove 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. 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 CDA 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. Maintenance inspection checklists for disconnection and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

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 the *<local jurisdiction>* 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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 local, state, and federal law.

4.7.8 Open Channel Stormwater Compliance Calculations

Grass Channels receive 10% retention value and are not an accepted total suspended solids practice for the storage volume (Sv) provided by the BMP (Table 0.39).

Table 0.39 Grass Channel Retention Value and Pollutant Removal

Retention Value	= 0.1× *Sv*
Accepted TSS Treatment Practice	N/A

Grass channels on amended soils receive 30% retention value for the storage volume (Sv) provided by the practice (Table 0.40).

Table 0.40 Grass Channel on Amended Soils Retention Value and Pollutant Removal

Retention Value	= 0.3 × *Sv*
Accepted TSS Treatment Practice	No

Dry swales receive 60% retention value and are an accepted TSS removal practice for the storage volume (Sv) provided by the practice (Table 0.41).

Table 0.41 Dry Swale Retention Value and Pollutant Removal

Retention Value	= 0.6 × *Sv*
Accepted TSS Treatment Practice	Yes

Wet swales receive 10% retention value and are an accepted TSS removal practice for the storage volume (Sv) provided by the BMP (Table 0.42).

Table 0.42 Wet Swale Retention Value and Pollutant Removal

Retention Value	= 0.1 × *Sv*
Accepted TSS Treatment Practice	Yes

Two Stage Ditches receive 10% retention value and are an accepted TSS removal practice for the storage volume (Sv) provided by the BMP (Table 0.45).

Table 0.43 Two Stage Ditch Retention Value and Pollutant Removal

Retention Value	= 0.1 × *Sv*
Accepted TSS Treatment Practice	Yes

RSC receive 10% retention value and are an accepted TSS removal practice for the storage volume (Sv) provided by the BMP (Table 0.46).

Table 0.44 RSC Retention Value and Pollutant Removal

Retention Value	= *Sv*
Accepted TSS Treatment Practice	Yes

All practices must be sized using the guidance detailed in Section 4.7.4 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 storage volume (Sv) or retention value from the total runoff volume for the 2-year through the 50-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN 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.

4.7.9 References

Anne Arundel County, Maryland. 2011. Regenerative Step Pool Storm Conveyance (SPSC), Design Guidelines. Revision 3: July 2011. Available at http://www.aacounty.org/DPW/Watershed/SPSCdesignguidelinesDec2012rev5.pdf

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

ASTM D448-12(2017), Standard Classification for Sizes of Aggregate for Road and Bridge Construction, ASTM International, West Conshohocken, PA, 2017, www.astm.org

Barrett, Michael E., Michael V. Keblin, Patrick M. Walsh, Joseph F. Malina, Jr., and Randall J. Charbeneau. 1998. Evaluation of the Performance of Permanent Runoff Controls: Summary and Conclusions. Center for Transportation Research Bureau of Engineering Research. The University of Texas at Austin. Available online at http://www.utexas.edu/research/ctr/pdf_reports/2954_3F.pdf

Charleston County. 2011. Charleston County Stabilization Specifications. Charleston County, SC.

Fuss, D., T. Garigen, S. Libes, and J. Dignam. 2010. Proceedings of the 2010 South Carolina Water Resources Conference, held October 13-14, 2010 at the Columbia Metropolitan Convention Center.

Haan, C.T., B.J Barfield., and J.C. Hayes, Design Hydrology and Sedimentology for Small Catchments. Academic Press, New York, 1994.

Jayakaran, A. D., S.M. Libes, and K.J. Owens. 2009. “Assessing suspended sediment transport potential and supply in an urbanizing coastal plains stream.” Report No. 2008SC55B, State Water Resources Research Institute Program, http://water.usgs.gov/wrri/08grants/2008SC55B.html

Mar, B.W., R.R. Horner, J.F. Ferguson, D.E. Spyridakis, E.B. Welch. 1982. Summary ¨C Highway Runoff Water Quality Study, 1977 ¨C 1982. WA RD 39.16. September, 1982.

Roanoke Virginia, Stormwater Design Manual. 2008. Stormwater Management Design Manual. Department of Planning Building and Development. Roanoke, Virginia.

South Carolina Department of Health and Environmental Control (SCDHEC). 2005. Stormwater Management BMP Handbook. Available online at http://www.scdhec.gov/Environment/WaterQuality/Stormwater/BMPHandbook/

USDA. 1954. Handbook of Channel of Design for Soil and Water Conservation. Stillwater Outdoor Hydraulic Laboratory and the Oklahoma Agricultural Experiment Station. SCS-TP-61, Washington, DC.

USDA-NRCS, 2007. Ch10, Two-Stage Channel Design In: Part 654, Stream Restoration Design National Engineering Handbook (210-VI-NEH), Bernard, J.F. Fripp & K.R. Robinson (Eds.). Washington, D.C.: USDA Natural Resources Conservation Service. Available online at http://directives.sc.egov.usda.gov/17770.wba

Virginia DCR Stormwater Design Specification No. 3: Grass Channels Version 1.8. 2010.

Virginia DCR Stormwater Design Specification No. 10: Dry Swales Version 1.8. 2010.

Virginia DCR Stormwater Design Specification No. 11: Wet Swales Version 1.8. 2010.

Ward., A.D, D. Mecklenburg, G.E. Powell, A.D. Jayakaran, and L.C. Brown. 2004. Two- Stage Channel Design Procedures. 2004 ASAE Specialty Conference. STREAMS

Washington State Department of Ecology. 2005. Stormwater Manual for Western Washington. State of Washington Department of Ecology. Available online at: https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Stormwater-manuals

4.8 Filtering Systems

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.					
Site Applicability		BMP Performance Summary			
Land Uses	Required Footprint	WQ Improvement: Moderate to High			
▪ Urban ▪ Suburban	**Small**	TSS[1]	Total N[1]	Bacteria[1]	
		80%	25-45%	???	
		Runoff Reductions			
Construction Costs	Maintenance Burden	Rate		Volume	
High	High	Low		Low	
Maintenance Frequency:		*SWRv*			
Routine	Non-Routine	F-1	F-2	F-3	F-4
At least annually	Every 5 years	0	0	0	0
Advantages/Benefits		Disadvantages/Limitation			
▪ Applicable to small drainage areas ▪ Good for highly impervious areas ▪ Good for water quality retrofits to existing developments		▪ High maintenance burden ▪ Not recommended for areas with high sediment content in stormwater or clay/silt runoff areas ▪ Relatively costly ▪ Possible odor problems, if not maintained ▪ Limited volume and rate control			
Components		Design considerations			
▪ Conveyance ▪ Pretreatment ▪ Sand bed (or Filtration) chamber ▪ Spillway/outlet system(s) ▪ Liner, as needed		▪ Typically requires 2 to 6 feet of head ▪ Maximum CDA of 2-5 acres ▪ Must drain within 40 hours ▪ In karst areas, water tight structure required ▪ Maintenance access			
Maintenance Activities					
▪ Inspect for clogging—rake first inch of sand ▪ Remove sediment from pretreatment areas		▪ Replace filter media as needed ▪ Clean spillway/outlet system(s)			

[1]*expected annual pollutant load removal*

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. 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.

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 the following:

F-1 Nonstructural sand filter

F-2 Surface sand filter

F-3 Three-chamber underground sand filter

F-4 Perimeter sand filter

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.

Filtering systems are typically not designed to provide stormwater detention, 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 by 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.

A nonstructural or surface sand filter is depicted in Figure 0.42, while Figure 0.43 through Figure 0.43 depict three-chamber underground sand filters.

Perimeter sand filters (Figure 0.45) are enclosed stormwater management practices that are typically located just below grade in a trench along the perimeter of parking lot, driveway, or other impervious surface. Perimeter sand filters consist of a pretreatment forebay and a filter bed chamber. Stormwater runoff is conveyed into a perimeter sand filter through grate inlets located directly above the system

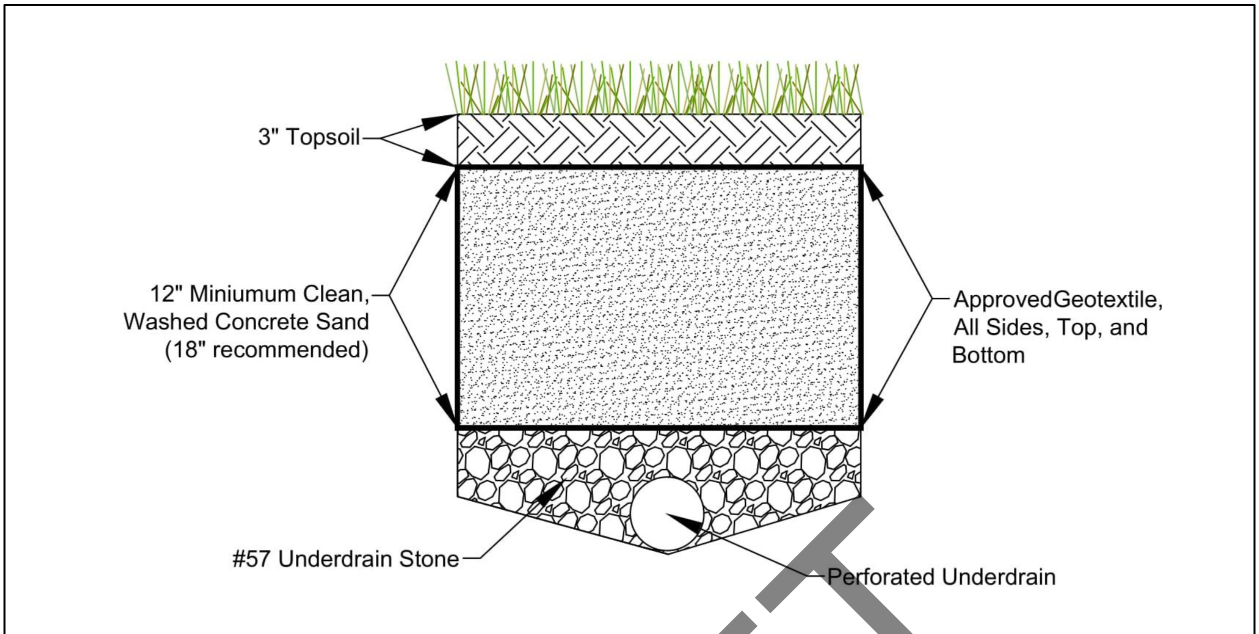

Figure 0.42 Typical schematic for a nonstructural or surface sand filter.
Note: Material specifications are indicated in Table 0.45.

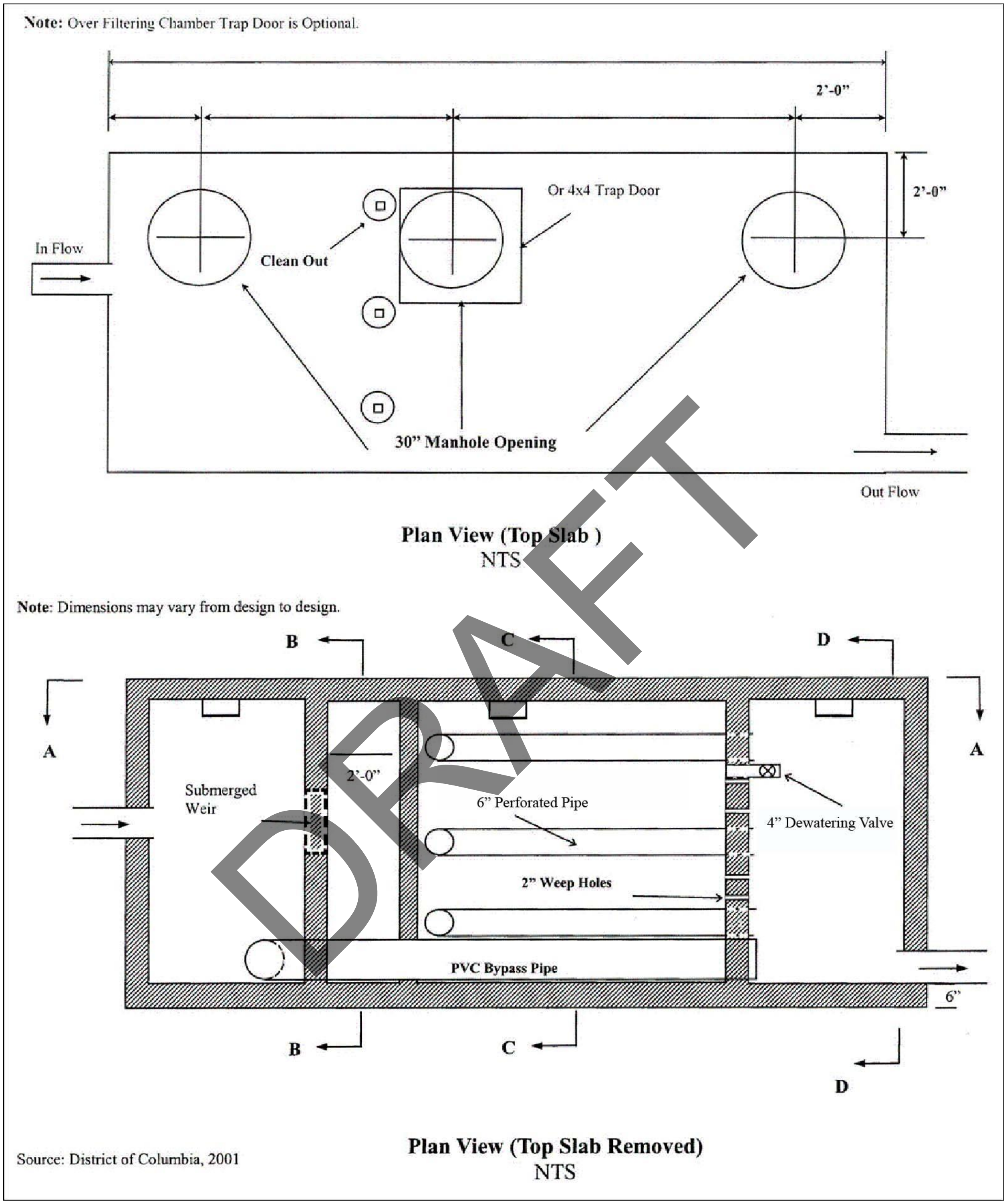

Figure 0.43 Example of a three-chamber underground sand filter (F-3) for separate sewer areas. Part A

Note: Material specifications are indicated in Table 0.45.

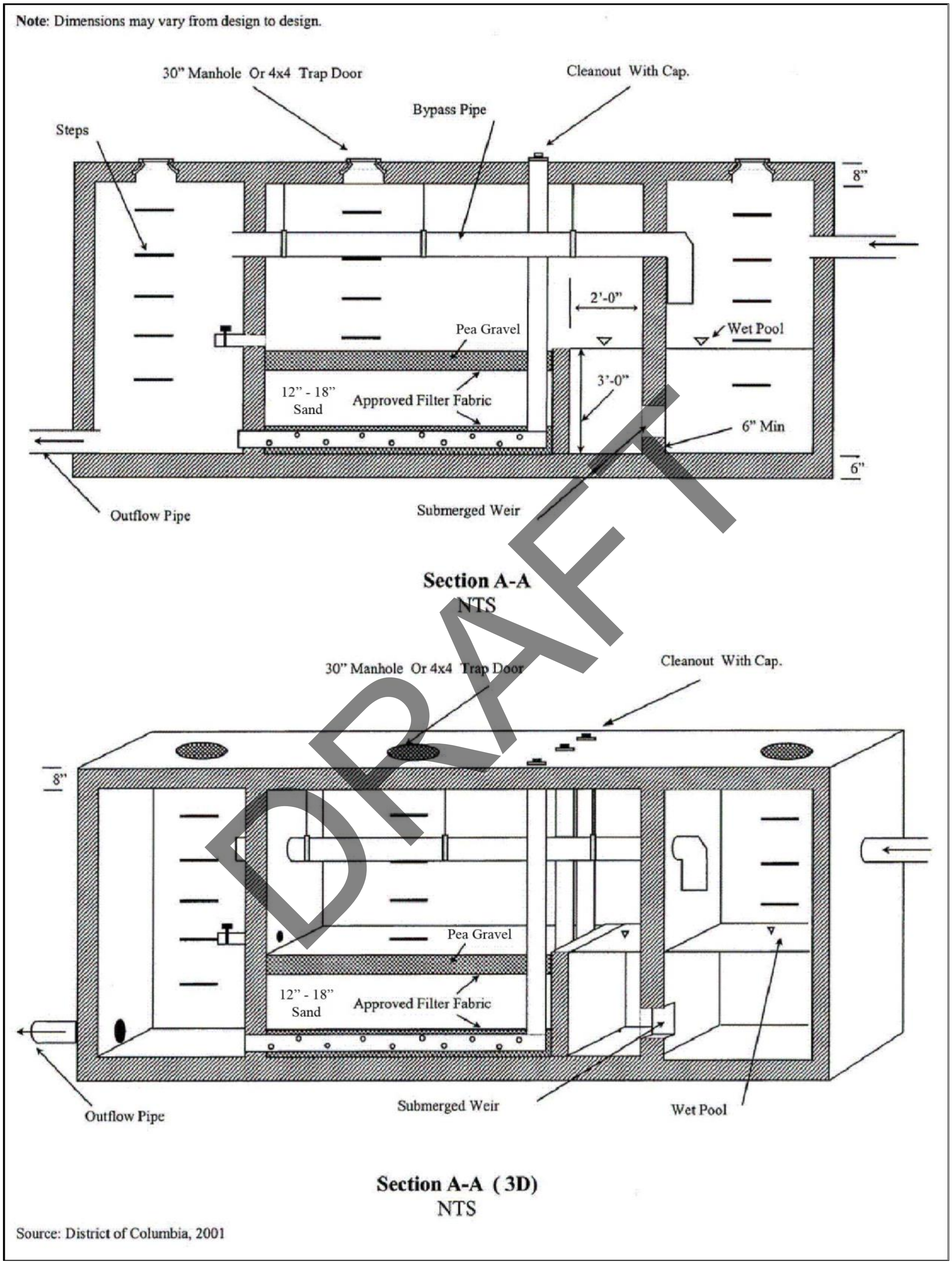

Figure 0.43 Example of a three-chamber underground sand filter (F-3) for separate sewer areas. Part B

Note: Material specifications are indicated in Table 0.45.

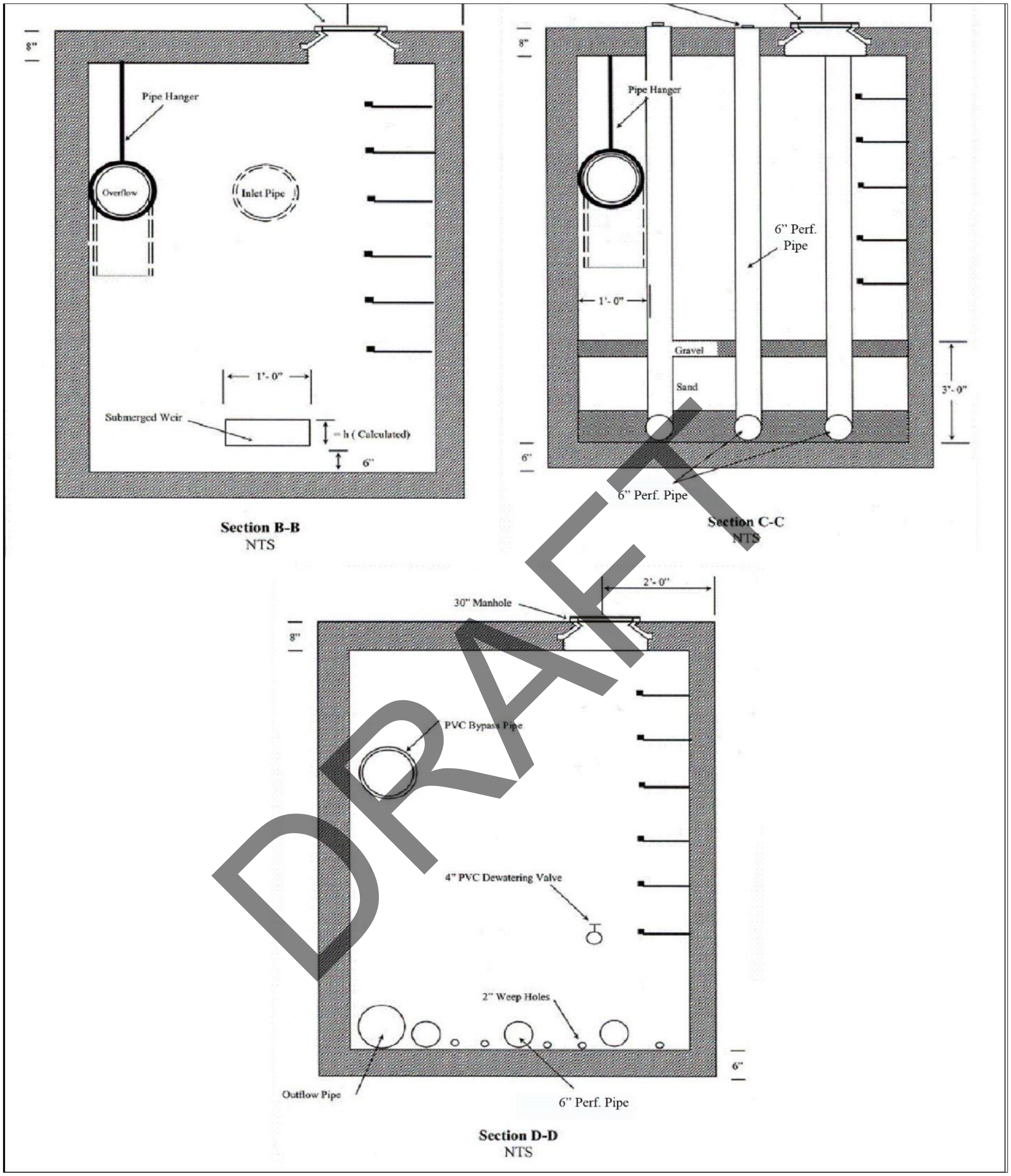

Figure 0.43 Example of a three-chamber underground sand filter (F-3) for separate sewer areas. Part C

Note: Material specifications are indicated in Table 0.45.

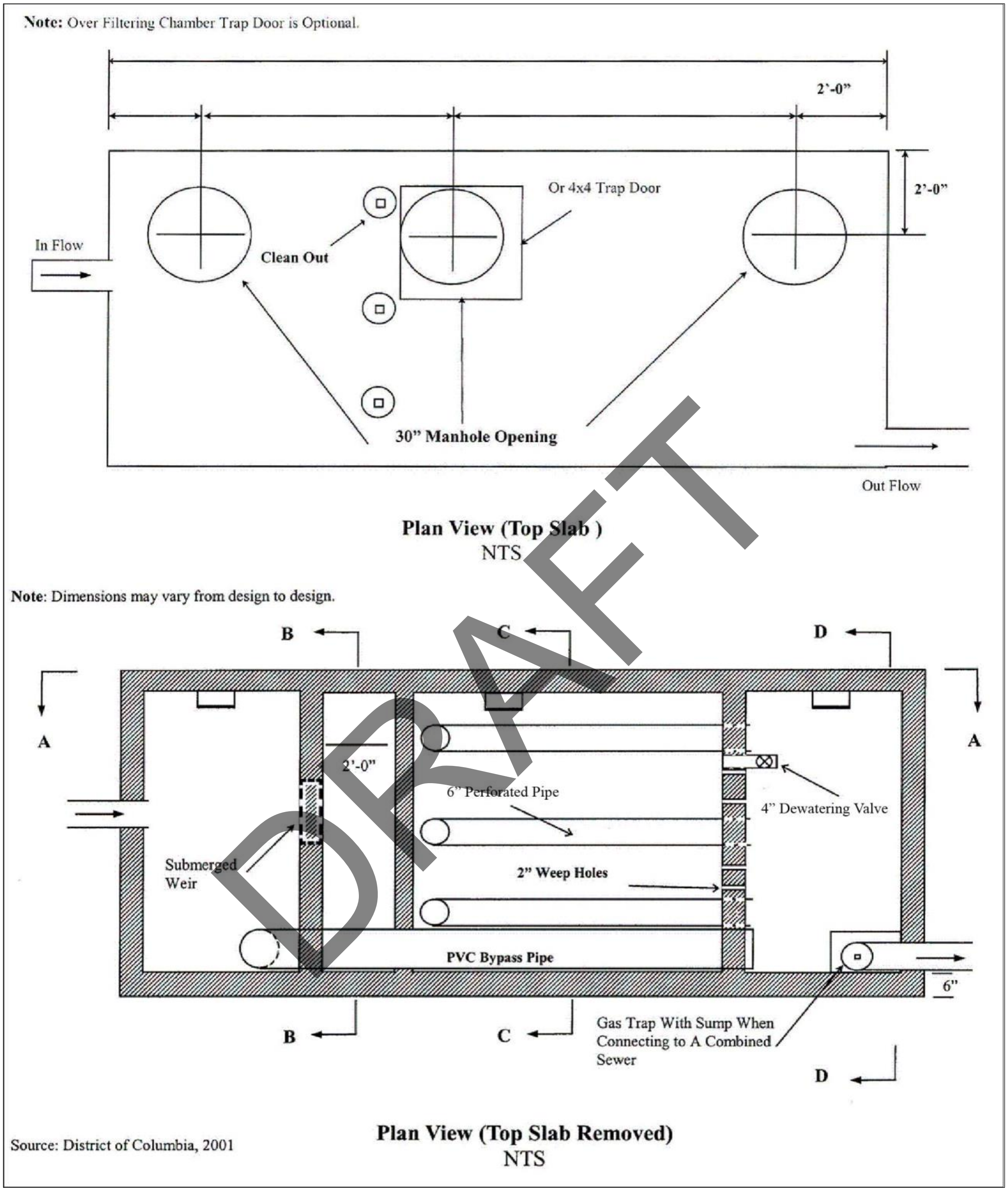

Figure 0.44 Example of a three-chamber underground sand filter (F-3) for combined sewer areas. Part A

Note: Material specifications are indicated in Table 0.45.

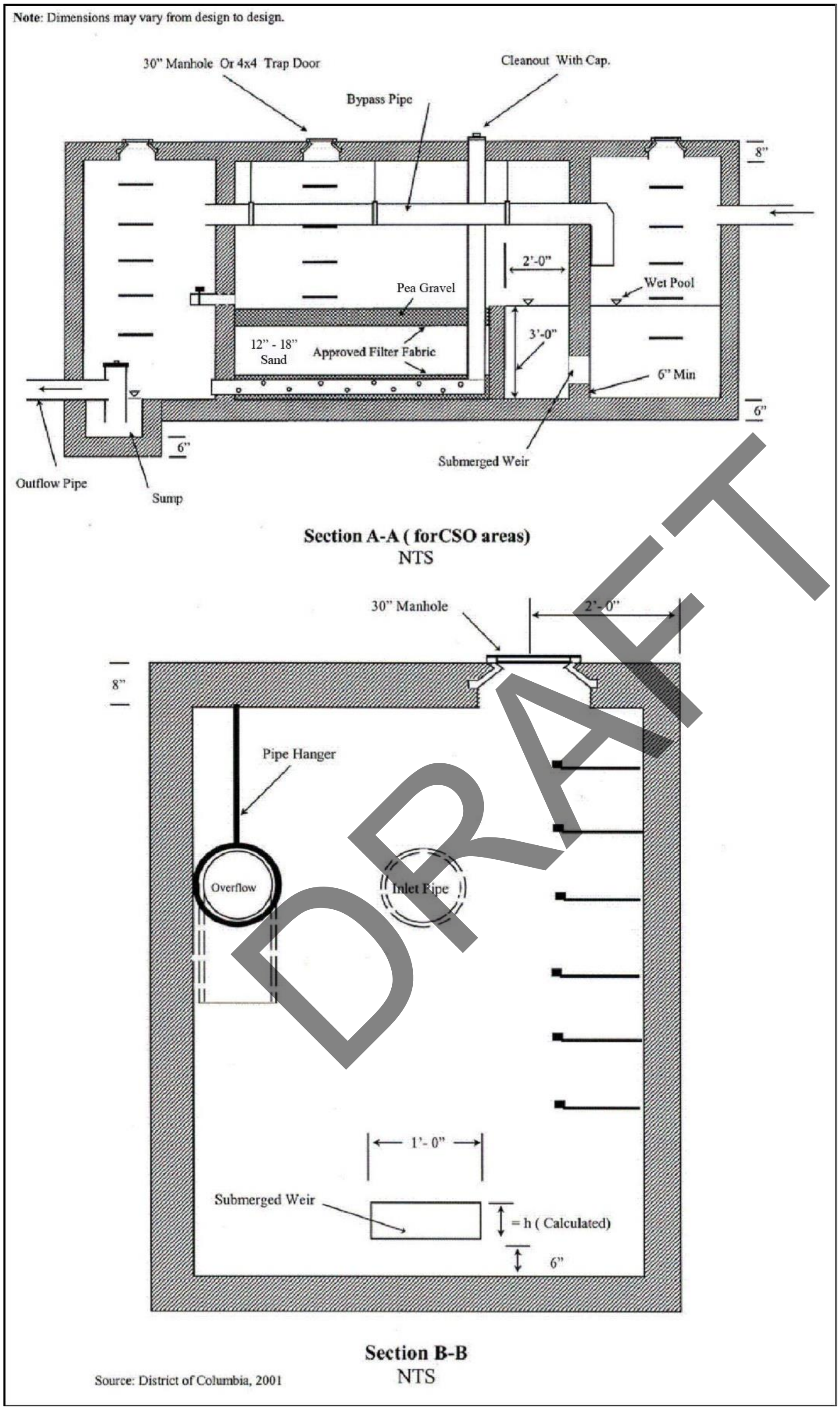

Figure 0.44 Example of a three-chamber underground sand filter (F-3) for combined sewer areas. Part B

Note: Material specifications are indicated in Table 0.45.

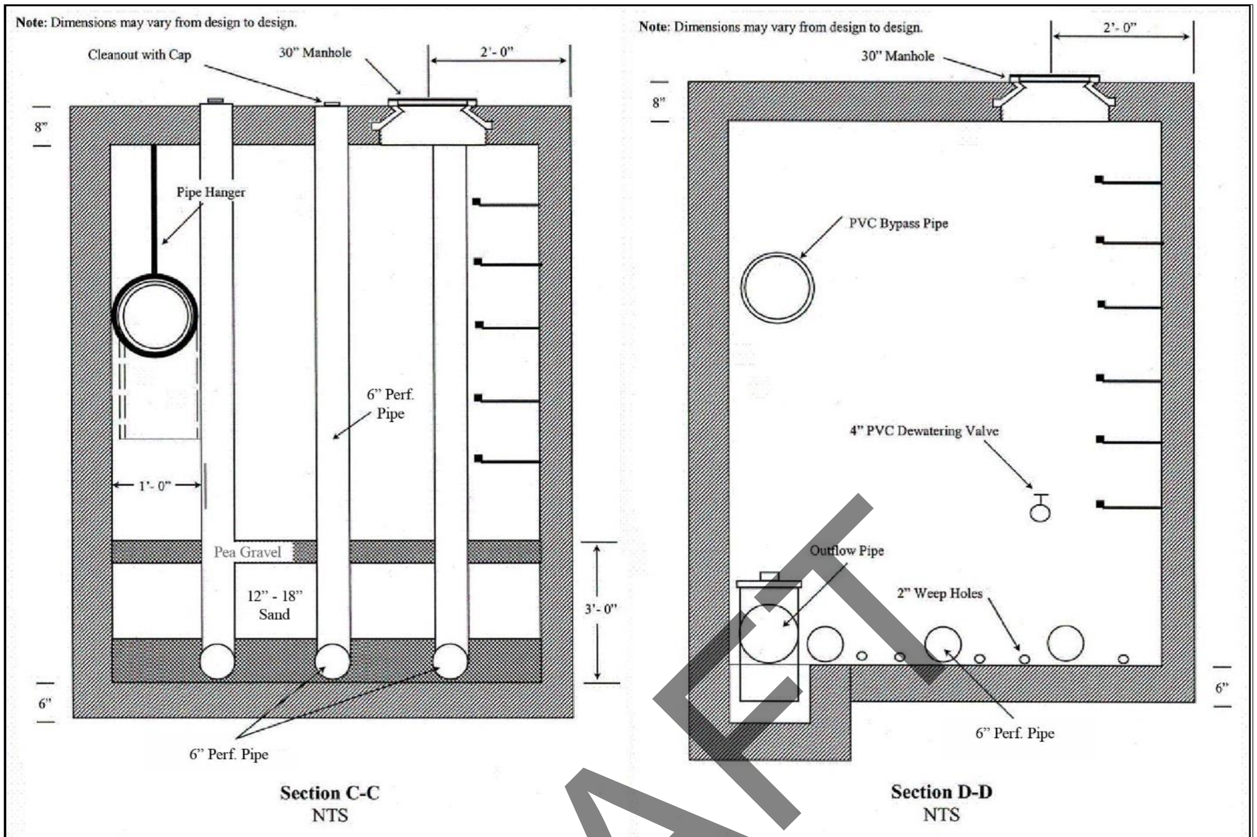

Figure 0.44 Example of a three-chamber underground sand filter (F-3) for combined sewer areas. Part C

Note: Material specifications are indicated in Table 0.45.

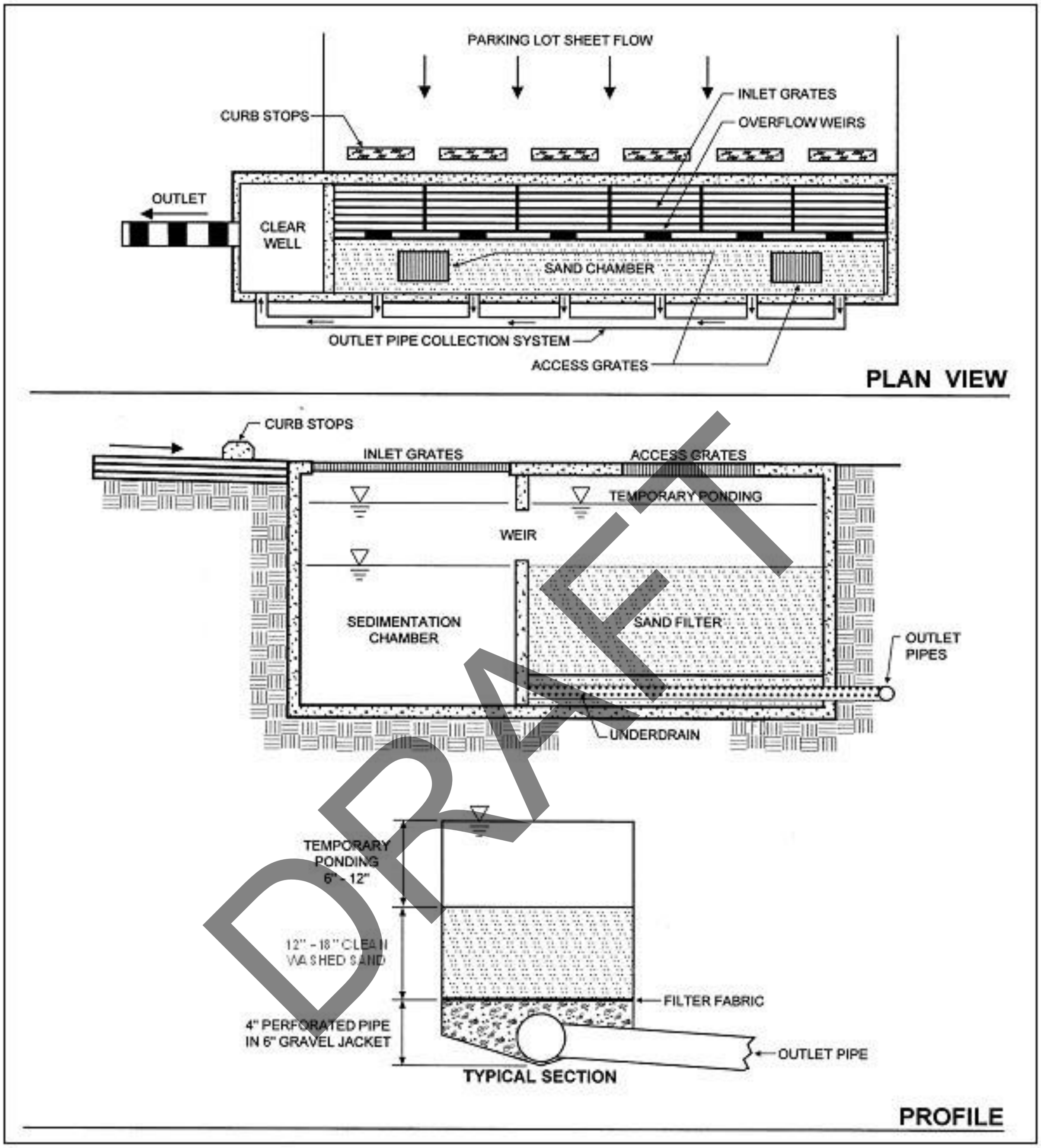

Figure 0.45 Example of a perimeter sand filter (F-4).
Note: Material specifications are indicated in Table 0.45

4.8.1 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. The designer must assure a standard separation distance of at least 0.5 feet between the groundwater table and the bottom invert of the filtering practice.

Contributing Drainage Area. Filters are best applied on small sites where the CDA is as close to 100% impervious as possible 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 4.8.5 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 CDAs in the past, but greater clogging problems have typically resulted.

Space Required. The amount of space required for a filter practice depends on the design variant selected. Surface sand filters typically consume about 2%–3% of the CDA, while perimeter sand filters typically consume less than 1%. 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%.

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 evaluate soil suitability. A geotechnical investigation is required for all underground stormwater BMPs, including underground filtering systems. Geotechnical testing requirements are outlined in Appendix B Geotechnical Information Requirements for Underground BMPs.

Setbacks. Filters should be set back at least 10 feet from the property line, and the bottom of the practice should be separated from groundwater by at least 0.5 feet.

Economic Considerations. Perimeter sand filters are expensive relative to other treatment practices, but may be the only option to treat small hotspot drainage areas.

4.8.2 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 40 hours (1.67 days) after a storm event to reduce the potential for nuisance conditions.

4.8.3 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% 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% 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% of the total design storm volume (inclusive).

4.8.4 Filtering Design Criteria

Detention time. All filter systems must be designed to drain the design storm volume from the filter chamber within 40 hours (1.67 days) 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 0.02 to 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 costlier maintenance.

Underdrain and Liner. Stormwater filters are normally designed with an impermeable liner and underdrain system that meet the criteria provided in Table 0.45 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 4.1 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% 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 pond (see Section 4.9Storage Practices).
- **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-4).** 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 or No. 57 stone layer on top of the sand layer. This gravel layer 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 2,000 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 of 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 0.45.

Table 0.45 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 pea gravel or 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 0.02–0.04 inches in diameter.
Choker Stone and/or Geotextile/Filter Fabric	For choker stone, a 2- to 4-inch layer of choker stone (e.g., typically ASTM D448 No. 8 or No. 89 washed gravel) should be placed between the sand layer and the underdrain stone. Alternatively, if available head is limited, an appropriate geotextile fabric that meets AASHTO M-288 Class 2, latest edition, requirements may be used. The geotextile fabric must have a flow rate of > 125 gpm/ft^2 (ASTM D4491) and an Apparent Opening Size (AOS) equivalent to a US No. 70 or No. 80 sieve.
Underdrain/Perforated Pipe	4- or 6-inch perforated schedule 40 PVC pipe, with three or four rows of 3/8-inch perforations at 6 inches on center.
Underdrain Stone	Use No. 57 stone or the ASTM equivalent (1-inch maximum).
Impermeable Liner	Where appropriate, use a PVC Geomembrane liner or equivalent.

Filter Sizing. Filtering devices are sized to accommodate a specified design storm volume (typically 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 0.24 is used to determine the required filter surface area.

Equation 0.24 Minimum Filter Surface Area for Filtering Practices

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

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_d	=	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% of the design storm volume prior to filtration (see Equation 0.25). 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 0.25 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 0.26 below.

Equation 0.26 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)

4.8.5 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.

4.8.6 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 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 Contributing Drainage Area.** Filtering practices should only be constructed after the CDA to the facility is completely stabilized, so sediment from the CDA does not flow into and clog the filter. If the proposed 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 regraded 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 ensure 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% of the water volume in a 24-hour period. See Appendix E Construction Inspection Checklists 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.

Construction phase inspection checklist for filters and the Stormwater Facility Leak Test form can be found in Appendix E Construction Inspection Checklists.

4.8.7 Filtering Maintenance Criteria

Maintenance of filters is required and involves several routine maintenance tasks, which are outlined in Table 0.46. 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 State 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 0.46 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 CDA 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 0.5 inch of rainfall, to evaluate the condition and performance of the filtering practice.

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

Maintenance inspection checklists for filters and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

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 the *<local jurisdiction>* 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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 local, state, and federal law.

4.8.8 Filtering Volume Compliance Calculations

Filtering practices receive 0% retention value. Filtering practices are an accepted total suspended solids (TSS) treatment practice for the storage volume (Sv) provided by the BMP (Table 0.47).

Table 0.47 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 4.8.4 Filtering Design Criteria.

4.8.9 References

ASTM D448-12(2017), Standard Classification for Sizes of Aggregate for Road and Bridge Construction, ASTM International, West Conshohocken, PA, 2017, www.astm.org

ASTM D4491 / D4491M-17, Standard Test Methods for Water Permeability of Geotextiles by Permittivity, ASTM International, West Conshohocken, PA, 2017, www.astm.org

Atlanta Regional Commission (ARC). 2001. Georgia Stormwater Management Manual, First Edition. Available online at: https://atlantaregional.org/natural-resources/water/georgia-stormwater-management-manual/

Claytor, R. and T. Schueler. 1996. Design of Stormwater Filtering Systems. Chesapeake Research Consortium and the Center for Watershed Protection. Ellicott City, MD. https://owl.cwp.org/

Hirschman, D., Collins, K., and T. Schueler. 2008. Technical Memorandum: The Runoff Reduction Method. Center for Watershed Protection and Chesapeake Stormwater Network. Ellicott City, MD.

Schueler, T., D. Hirschman, M. Novotney, and J. Zielinski. 2007. Urban Stormwater Retro- fit Practices, Version 1.0, Urban Subwatershed Restoration Manual No. 3

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.

4.9 Storage Practices

Storage Practices							
Definition: Practices that are explicitly designed to provide stormwater detention (2 - 50-year, and/or flood control).							

Site Applicability		BMP Performance Summary		
Land Uses	Required Footprint	WQ Improvement: Low		
		TSS[1]	Total N[1]	Bacteria[1]
▪ Urban ▪ Suburban ▪ Rural	**Medium**	N/A	N/A	N/A

Construction Costs	Maintenance Burden	Runoff Reductions	
		Rate	Volume
Moderate	Low	Moderate	High

Maintenance Frequency:		*SWRv*			
Routine	Non-Routine	S-1	S-2	S-3	S-4
Quarterly	Every 10-15 years	0	0	0	0

Advantages/Benefits	Disadvantages/Limitation
▪ Runoff reduction and flood control ▪ Typically less costly than stormwater (wet) ponds for equivalent flood storage ▪ Provides recreational and other open space opportunities between storm runoff events	▪ Minimal water quality treatment ▪ Best suited to large CDAs (at least 10 acres) ▪ Tends to re-suspend sediment

Components	Design considerations
▪ Conveyance ▪ Inlets/outlets ▪ Forebay ▪ Ponding area with available storage ▪ Micropool ▪ Spillway system(s) ▪ Liners, as needed	▪ Applicable for drainage areas up to 75 acres ▪ Depth to high water table must be at least 6 inches ▪ Drawdown of 24 to 48 hours ▪ Shallow pond with large surface area performs better than deep pond of same volume ▪ Maintenance access

Maintenance Activities	
▪ Remove debris (inlets/outlets/basin surface) ▪ Remove sediment buildup ▪ Repair and revegetate eroded areas.	▪ Perform structural repairs to inlet and outlets. ▪ Mow unwanted vegetation

[1] *expected annual pollutant load removal*

Storage practices are another common BMP used to address stormwater runoff volume (Figure 0.46**). They temporarily detain water to reduce peak flows.**

Figure 0.46 Dry Extended Detention Pond (Photo: Center for Watershed Protection)

Definition. Storage practices are explicitly designed to provide stormwater detention (2 - 50-year, and/or flood control). Design variants include the following:

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 concrete or plastic pipe (see Figure 0.47). 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 SDAs. An outlet structure restricts stormwater flow, so it backs up and is stored within the basin (see Figure 0.48). 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.

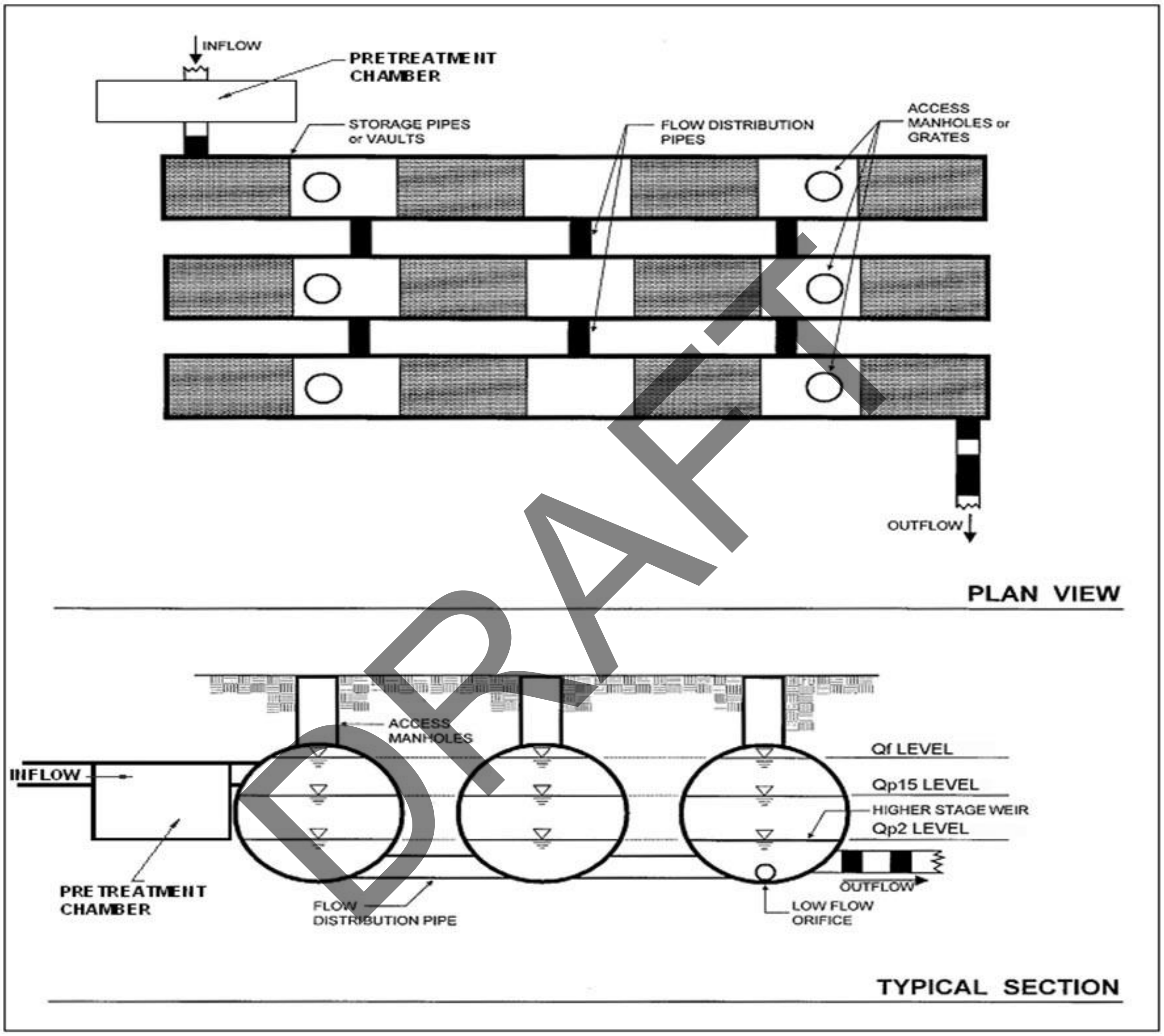

Figure 0.47 Example of an underground detention vault and/or tank (S-1).

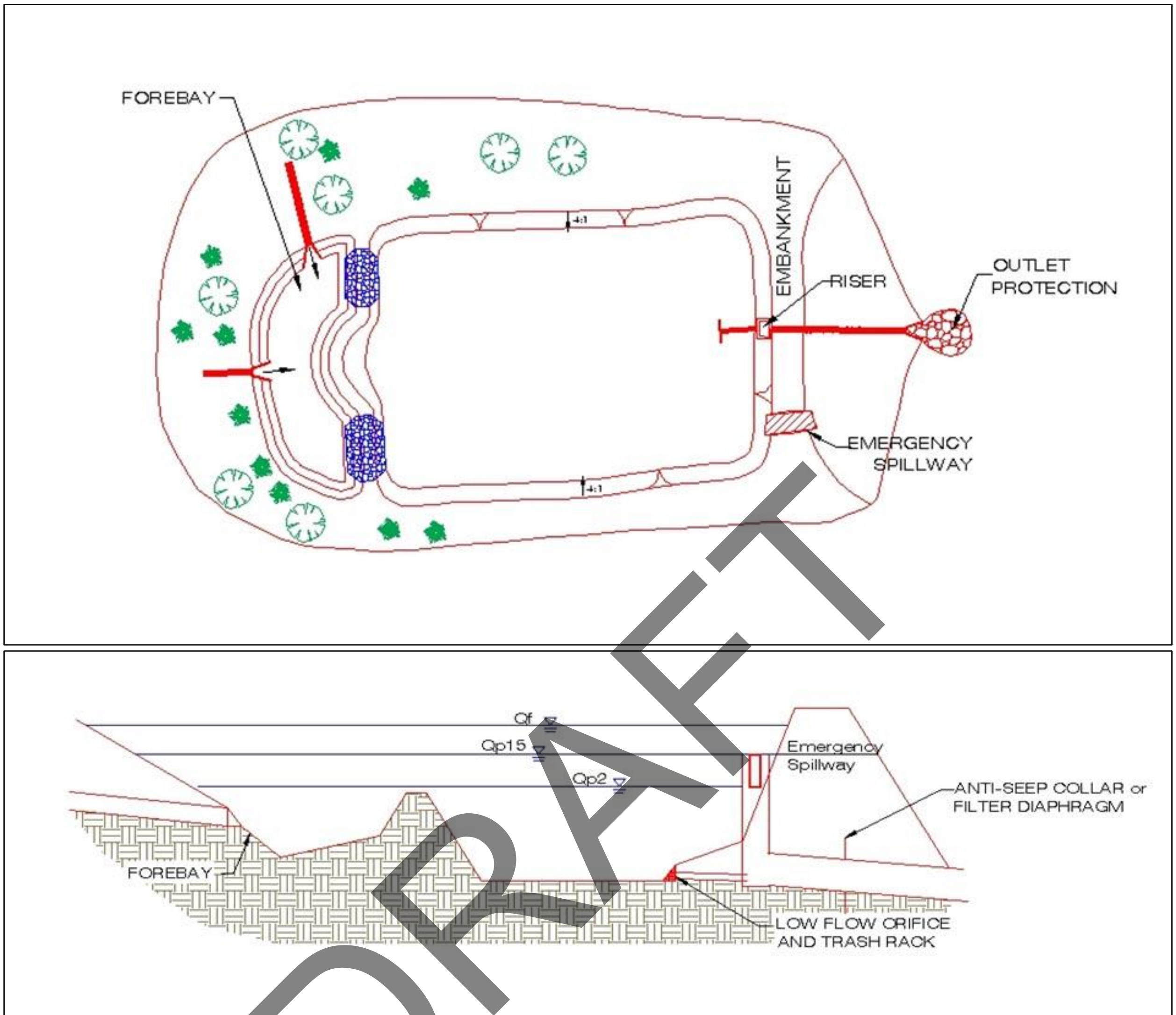

Figure 0.48 Example of a dry detention pond (S-2).

4.9.1 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 practice requires a footprint of 1%–3% of its CDA, depending on the depth of the pond or storage vault (i.e., the deeper the practice, the smaller footprint needed).

Contributing Drainage Area. A CDA 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 NRCS CN that reflects the volume reduction of upland practices and likely reduce the size and cost of detention (see Storage Practice Sizing in Section 4.8.4 Storage Design Criteria).

The maximum CDA 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, stormwater cannot flow via baseflow from storage practices to the traditional pavement base layer, existing structure foundations, or future foundations which may be built on adjacent properties. Setbacks to structures and property lines must be at least 10 feet, and adequate waterproofing protection must be provided for foundations and basements.

Depth to Water Table. Dry ponds are not allowed if the water table will be within 0.5 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 high water table areas.

Tidal Impacts. The outlet of a dry detention practice should be located above the tidal mean high water elevation. In tidally impacted areas, detention practices may have minimal benefit, and re- questing a variance for detention requirements may be an option.

Tailwater Conditions. The flow depth in the receiving channel should be considered when determining outlet elevations and discharge rates from the dry detention practice. Design tailwater condition elevation shall be supported by a reasonable resource and/or analysis. For direct discharges to tidal waters, a king tide evaluation shall accompany the tailwater condition evaluation.

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 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 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 B Geotechnical Information Requirements for Underground BMPs.

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.

Economic Considerations. Underground detention can be expensive, but often allows for greater use of a development site. Dry detention ponds are generally inexpensive to construct and maintain. Depending upon the type of development, dry detention practices may be required to treat a larger volume of water than other BMPs. Dry detention practices must store 1 inch of runoff from the site, whereas infiltration practices and other BMPs must capture 1 inch of runoff from only the impervious cover on a site.

4.9.2 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 2.10 Hydrology Methods for a summary of acceptable hydrologic 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 2- 50-year frequency storm event 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 dissipators 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 25-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 feet per second 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 SWMP 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 riprap 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 2.11 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 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 C361) 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 the following:
  - Providing a micropool at the outlet structure. For more information on micropool extended detention ponds see Section 0 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 <*local jurisdiction*>.
- **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).

4.9.3 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% of the storage practice’s CDA.
- 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 2-year event and 6 feet per second for the 25-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 0 Proprietary Practices for information on approved proprietary practices.

4.9.4 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%–1%.
- **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 CDA served by these “closer” inlets must constitute no more than 20% of the total CDA.

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 <*local jurisdiction*>, a 5H:1V 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, a hinged door, or removable panel. Removable panels must be designed with sufficient support so they cannot fall through the opening into the vault when removed.

Outlets. Trash racks shall be provided for low-flow pipes and for risers not having anti-vortex devices.

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 <*local jurisdiction*>. 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 <*local jurisdiction*>. 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 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 - 50-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 2.10 Hydrology Methods for a summary of acceptable hydrologic 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 NRCS CN that reflects the volume reduction of upland practices to compute the 2- 50-year frequency storm event that must be treated by the storage practice.

4.9.5 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.

4.9.6 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. 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 Contributing Drainage Area.** Dry ponds should only be constructed after the CDA 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 regraded to design dimensions after the original site construction is complete.

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

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

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. E**nsure 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 and at the design elevation.

Step 8: **Construct the Embankment and any Internal Berms. Construct the embankment and berms** 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 riprap 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)

Construction phase inspection checklist for storage practices and the Stormwater Facility Leak Test form can be found in Appendix E Construction Inspection Checklists.

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.

4.9.7 Storage Maintenance Criteria

Typical maintenance activities for storage practices are outlined in Table 0.48. 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 0.48 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 CDA, inlets, and facility surface are clear of debris. ▪ Ensure that the CDA 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, riprap 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.

Maintenance inspection checklists for extended detention ponds and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

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 the *<local jurisdiction>* 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 Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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 local, state, and federal law.

4.9.8 Storage Volume Compliance Calculations

Storage practices receive no retention value and are not an accepted total suspended solids (TSS) treatment practice (Table 0.49). These practices should be used only for control of larger storm events.

Table 0.49 Storage Retention Value and Pollutant Removal

Retention Value	= 0
Accepted TSS Treatment Practice	No

4.9.9 References

ASTM C361-16, Standard Specification for Reinforced Concrete Low-Head Pressure Pipe, ASTM International, West Conshohocken, PA, 2016, www.astm.org

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.

4.10 Ponds

<table>
<tr><th colspan="8">Ponds</th></tr>
<tr><td colspan="8">Definition: 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.</td></tr>
<tr><th colspan="2">Site Applicability</th><th colspan="6">BMP Performance Summary</th></tr>
<tr><th>Land Uses</th><th>Required Footprint</th><th colspan="6">WQ Improvement: Moderate to High</th></tr>
<tr><td rowspan="3">▪ Urban
▪ Suburban
▪ Rural</td><td rowspan="3">Medium</td><td colspan="2">TSS[1]</td><td colspan="2">Total N[1]</td><td colspan="2">Bacteria[1]</td></tr>
<tr><td colspan="2">60-85%</td><td colspan="2">25-45%</td><td colspan="2">70%</td></tr>
<tr><th colspan="6">Runoff Reductions</th></tr>
<tr><th>Construction Costs</th><th>Maintenance Burden</th><th colspan="3">Rate</th><th colspan="3">Volume</th></tr>
<tr><td>Moderate</td><td>Moderate</td><td colspan="3">High</td><td colspan="3">High</td></tr>
<tr><th colspan="2">Maintenance Frequency:</th><th colspan="6">SWRv</th></tr>
<tr><th>Routine</th><th>Non-Routine</th><th colspan="2">C-1</th><th colspan="2">C-2</th><th colspan="2">C-3</th></tr>
<tr><td>At least annually</td><td>Every 5-7 years</td><td colspan="2">10% of Sv</td><td colspan="2">10% of Sv</td><td colspan="2">10% of Sv</td></tr>
<tr><th colspan="2">Advantages/Benefits</th><th colspan="6">Disadvantages/Limitation</th></tr>
<tr><td colspan="2">▪ Moderate to high pollutant removal
▪ Can be designed as a multi-functional BMP
▪ Cost effective
▪ Good for sites with high water table and/or poorly drained soils
▪ Wildlife habitat potential
▪ High community acceptance when integrated into a development</td><td colspan="6">▪ Requires large amount of flat land (1-3% of CDA)
▪ Must be properly designed, installed, and maintained to avoid nuisance problems
▪ Routine sediment cleanout may be needed
▪ Potential for thermal impacts downstream</td></tr>
<tr><th colspan="2">Components</th><th colspan="6">Design considerations</th></tr>
<tr><td colspan="2">▪ Conveyance
▪ Forebay
▪ Ponding area with available storage
▪ Micropool
▪ Spillway system(s)
▪ Liners, as needed</td><td colspan="6">▪ CDA of 10 to 25 acres and slopes <15%
▪
▪ Minimum length to width ratio = 3:1
▪ Maximum depth of permanent pool = 8’
▪ 3:1 side slopes or flatter around pond perimeter</td></tr>
<tr><th colspan="8">Maintenance Activities</th></tr>
<tr><td colspan="2">▪ Remove debris from inlet and outlet structures
▪ Maintain side slopes/remove invasive vegetation</td><td colspan="6">▪ Monitor sediment accumulation and remove periodically</td></tr>
</table>

[1] *expected annual pollutant load removal*

Stormwater ponds are widely applicable for most land uses and are best suited for larger drainage areas (Figure 0.49); however, they 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 - 50-year or flood control events) to manage.

Stormwater ponds receive only 10% stormwater retention value and should be considered mainly for management of larger storm events. Stormwater ponds have both community and environmental concerns (see Section 4.10.1 Pond Feasibility Criteria) that should be considered before choosing stormwater ponds as the appropriate stormwater practice on site.

Figure 0.49 Wet Pond (Photo: Denise Sanger)

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 best suited for larger SDAs. Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to resuspension 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 the following (see Figure 0.50 and Figure 0.51):

C-1 Micropool extended detention pond

C-2 Wet pond

C-3 Wet extended detention pond

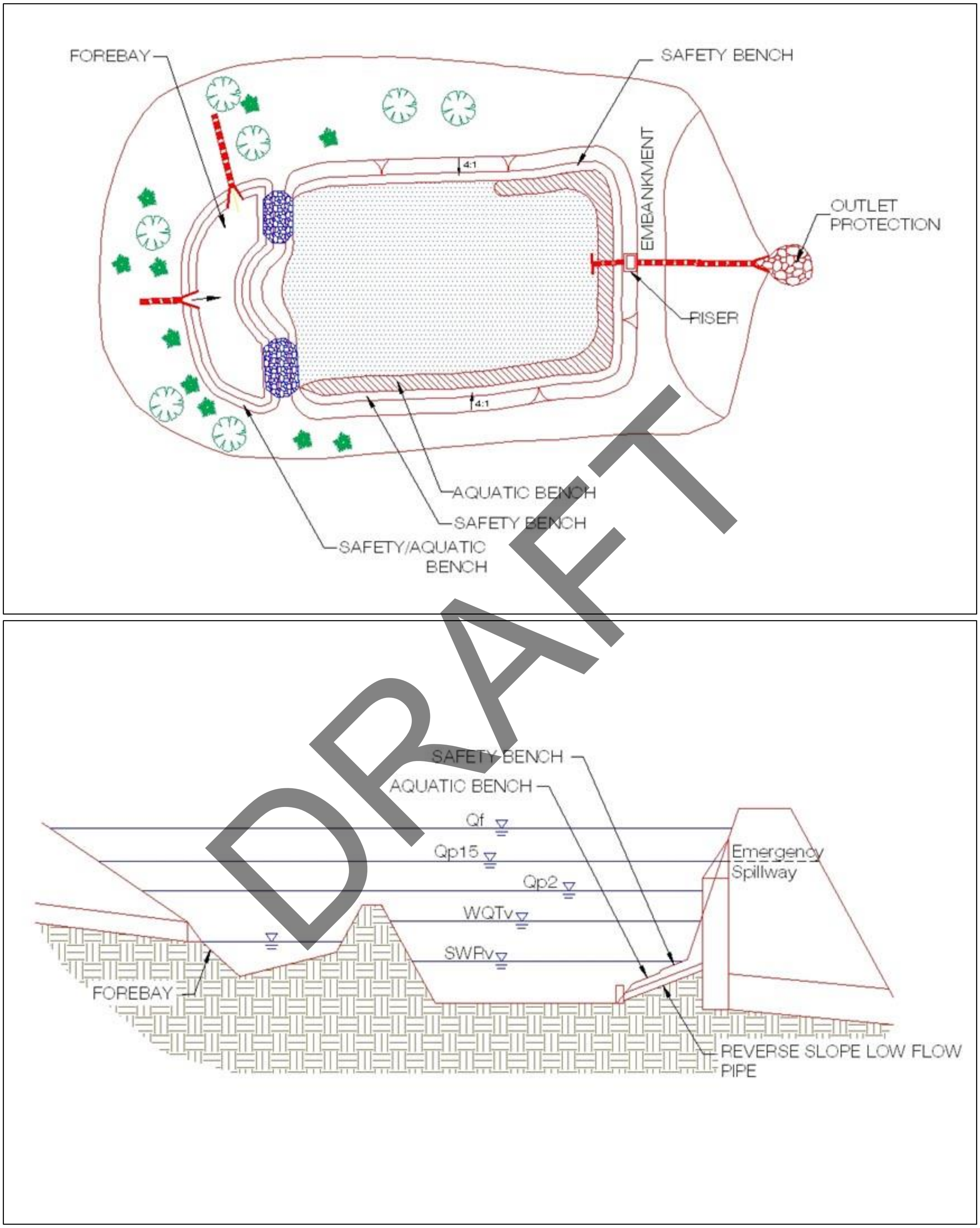

Figure 0.50 Design schematics for a wet pond (C-2).

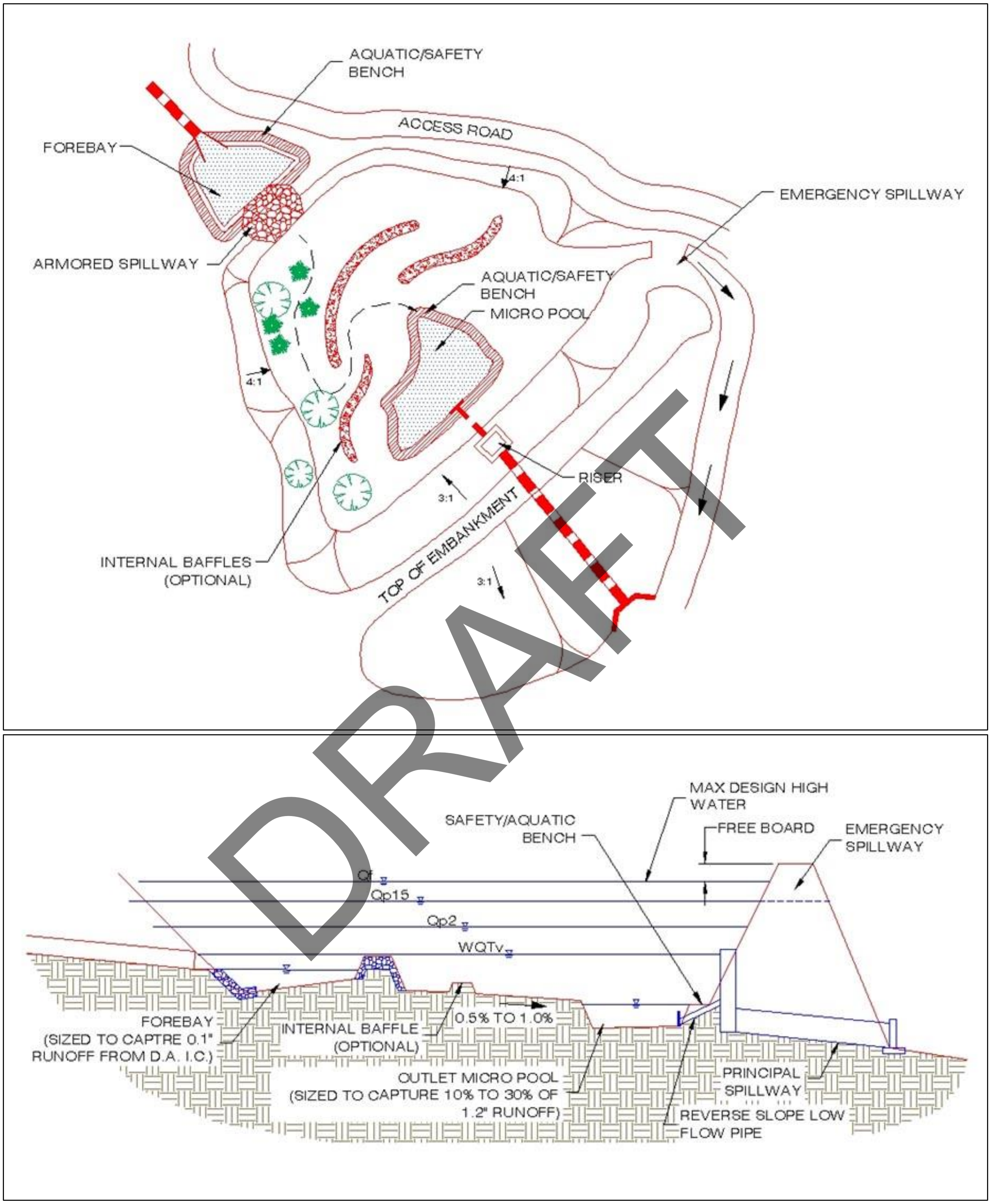

Figure 0.51 Typical extended detention pond (C-3) details.

4.10.1 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 0.28 in Section 4.10.4 Pond Design Criteria.

Contributing Drainage Area. A CDA of 10 to 25 acres is typically recommended for ponds to maintain constant water elevations. Ponds can still function with CDAs 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%–3% of its CDA, depending on the pond's depth.

Site Topography. Ponds are best applied when the grade of contributing slopes is less than 15%.

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 cannot flow via baseflow from stormwater ponds to the traditional pavement base layer, existing structure foundations, or future foundations which may be built on adjacent properties. Setbacks to structures and property lines must be at least 10 feet and adequate waterproofing 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 stormwater ponds 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.

Tailwater Conditions. The flow depth in the receiving channel should be considered when determining outlet elevations and discharge rates from wet pond. Design tailwater condition elevation shall be supported by a reasonable resource and/or analysis. For direct discharges to tidal waters, a king tide evaluation shall accompany the tailwater condition evaluation.

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 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 3.42). Geotechnical tests should be conducted to determine the saturated hydraulic conductivity and other subsurface properties of the soils beneath the proposed pond.

Use of or Discharges to Natural Wetlands. Ponds cannot be located within State waters, including wetlands, without obtaining a Section 404 permit or other permissions 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 US Army COE permits under Clean Water Act Section 401 and Section 404 or other permissions from the appropriate state or federal regulatory agency.

Economic Considerations. Wet detention ponds tend to have low construction costs and low space demands (in terms of the land area needed to treat a given volume of water) relative to other LID practices. In addition, the soil excavated to construct ponds can be used as fill, which is often needed for construction on low-lying coastal areas.

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 CDAs.
- 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. Consideration of Better Site Design Principles is implicit with permitting decisions related to clearing of existing forest cover.
- 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).

4.10.2 Pond Conveyance Criteria

Internal Slope. The longitudinal slope of the pond bottom should be at least 0.5% 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 *<local jurisdiction>*.

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 feet per second) 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 riprap 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 2.11 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% 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.

4.10.3 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% of the pond's CDA.
- 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 2-year event, and 6 feet per second for the 25-year event.
- Direct maintenance access for appropriate equipment shall be provided to each forebay.

4.10.4 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 8 feet unless the pond is designed for multiple uses.

Micropool. A micropool is a 3- to 6-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%–25% of the 85th or 95th percentile 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%.
- **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, 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 0.50;
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 *<local jurisdiction>*.

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 0.50. Other synthetic liners can be used if the designer can supply supporting documentation that the material will achieve the required performance.

Table 0.50 Clay Liner Specifications

Property	Test Method	Unit	Specification
Permeability	ASTM D2434	cm/s	1×10^{-6}
Plasticity Index of Clay	ASTM D4318	%	Not less than 15
Liquid Limit of Clay	ASTM D2216	%	Not less than 30

Clay Particles Passing	ASTM D422	%	Not less than 30
Clay Compaction	ASTM D2216	%	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 (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 1 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 drain pipe 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 will not normally be inundated and 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 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.
- 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-foot-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 5H:1V.
- 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 - 50-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 2.10 Hydrology Methods for a summary of acceptable hydrologic 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 NRSC CN that reflects the volume reduction of upland practices to compute the 2- 50-year frequency storm event 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 0.27). The total Sv cannot exceed the design SWRv.

Equation 0.27 Pond Storage Volume

$$Sv = Pond\ permanent\ pool\ volume$$

- **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 0.28, 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 0.28 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 inches 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 0.29 can be used to convert the baseflow, measured in cubic feet per second (cfs), to pond-inches:

Equation 0.29 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, converting cfs to ft^3/month
12	=	conversion factor, converting feet to inches
SA	=	surface area of pond (ft^2)

4.10.5 Pond Landscaping Criteria

Pond Benches. The perimeter of all deep pool areas (4 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%.
- 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 4.1.5 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 bare root and 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).

4.10.6 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 versus 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 *<local jurisdiction>* must be obtained before any sediment pond can be used as for stormwater management.

Step 2: **Stabilize the Contributing Drainage Area.** Ponds should only be constructed after the CDA 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 regraded to design dimensions after the original site construction is complete.

Step 3: **Assemble Construction Materials on Site.** Inspect construction materials to ensure 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: **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 riprap 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 4.10.5 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)

Construction phase inspection checklist for ponds can be found in Appendix E Construction Inspection Checklists.

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.

4.10.7 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 0.51). 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.

Table 0.51 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 4.11.6 Stormwater Wetland Landscaping Criteria. ▪ Stabilize any bare or eroding areas in the CDA 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 through October), depending on rainfall.

Frequency	Maintenance Items
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

Sediment removal in the pond pretreatment forebay should occur every 5 to 7 years or after 50% 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 pollutant hotspot land use, as the sediment could be potentially toxic or hazardous (Weinstein et al., 2008). In lieu of local regulations for sediment testing, the parameters in Table 0.52 may be used.

Table 0.52 Ceiling Levels Governing Management of Accumulated Sediment[1]

Parameter	Ceiling Level (ppm or mg/kg)
Total Arsenic	8
Total Cadmium	10
Total Chromium	100
Total Lead	250
pH	Less than 5 or greater than 10 standard units
Electrical Conductivity	8 deciSiemens/meter (dS/m) at 25°C
[1] *excerpt from Wisconsin Administrative Code NR 528.03, Table 2*	

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. For information on chemical control methods for aquatic plants, consult Clemson's fact sheet entitled "Aquatic Weed Control Overview" available online at http://www.clemson.edu/extension/hgic/plants/other/landscaping/hgic1714.html.

Maintenance Inspections. Maintenance of a pond is driven by annual inspections by a qualified professional who evaluates the condition and performance of the pond. Based on inspection results, specific maintenance tasks will be triggered.

Maintenance inspection checklist for stormwater ponds and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

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 the *<local jurisdiction>* 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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 local, state, and federal law. However, sediment testing may be needed prior to sediment disposal because sediments excavated from ponds could be contaminated.

4.10.8 Pond Stormwater Compliance Calculations

Stormwater ponds receive 10% retention value and are an accepted total suspended solids (TSS) treatment practice for the storage volume (Sv) provided by the BMP (Table 0.53).

Table 0.53 Pond Retention Value and Pollutant Removal

Retention Value	= 0.1 × *Sv*
Accepted TSS Treatment Practice	Yes

The retention achieved by ponds 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 through the 100-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN 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.

4.10.9 References

ASTM C361-16, Standard Specification for Reinforced Concrete Low-Head Pressure Pipe, ASTM International, West Conshohocken, PA, 2016, www.astm.org

ASTM D2216-10, Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass, ASTM International, West Conshohocken, PA, 2010, www.astm.org

ASTM D2434-68(2006), Standard Test Method for Permeability of Granular Soils (Constant Head) (Withdrawn 2015), ASTM International, West Conshohocken, PA, 2006, www.astm.org

ASTM D4318-17, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, ASTM International, West Conshohocken, PA, 2017, www.astm.org

ASTM D422-63(2007)e2, Standard Test Method for Particle-Size Analysis of Soils (Withdrawn 2016), ASTM International, West Conshohocken, PA, 2007, www.astm.org

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

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., C. Apperson, and W. Lord. 2005. “Mosquito Control for Stormwater Facilities.” Urban Waterways. North Carolina State University and North Carolina Cooperative Extension. Raleigh, NC.

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.

Ladd, B and J. Frankenburg. 2003. Management of Ponds, Wetlands and Other Water Reservoirs. Purdue Extension. WQ-41-W.

Mallin, M. 2000. Effect of human development on bacteriological water quality in coastal watersheds. Ecological Applications 10(4):1047-1056.

Mallin, M.A., S.H. Ensign, Matthew R. McIver, G. Christopher Shank, and Patricia K. Fowler. 2001. Demographic, landscape, and meteorological factors controlling the microbial pollution of coastal waters. Hydrobiologia 460(1-3):185-193.

Messersmith, M.J. 2007. Assessing the hydrology and pollutant removal efficiencies of wet detention ponds in South Carolina. MS. Charleston, S.C. College of Charleston, Master of Environmental Studies.

Minnesota Stormwater Steering Committee (MSSC). 2005. Minnesota Stormwater Manual. Emmons & Oliver Resources, Inc. Minnesota Pollution Control Agency. St. Paul, MN.

Orscheln, N., and Giacolne, K., 2013 Resident Canada Geese: Management Options. SC Waterways. Clemson Cooperative Extension. Available online at: http://www.clemson.edu/extension/hgic/water/resources_stormwater/

Santana, F., J. Wood, R. Parsons, and S. Chamberlain. 1994. Control of Mosquito Breeding in Permitted Stormwater Systems. Southwest Florida Water Management District. Brooksville, FL.

Smith, E.M. 2012. Nutrient-Organic Matter Dynamics in Stormwater ponds: Implications for Stormwater Management and the Role of Ponds as Sources of Coastal Water Quality Impairment. Paper presented at the South Carolina Water Resources Conference, Columbia SC. Available online at: http://tigerprints.clemson.edu/cgi/viewcontent. cgi?article=1060&context=scwrc

Schueler, T, 1992. Design of Stormwater Wetland Systems. Metropolitan Washington Council of Governments. Washington, DC.

Virginia Department of Conservation and Recreation (VA DCR). 1999. Virginia Stormwater Management Handbook, first edition.

Virginia DCR Stormwater Design Specification No. 14: Wet Ponds Version 1.8. 2010.

Virginia DCR Stormwater Design Specification No. 15: Extended Detention (ED) Pond Version 1.8. 2010.

VA Department of Conservation and Recreation (VA DCR). 1999. Virginia Stormwater Management Handbook, first edition.

Weinstein, J.E., K.D. Crawford, and T.R. Garner. 2008. Chemical and Biological Contamination of Stormwater Detention Pond Sediments in Coastal South Carolina. Available at http://www.scseagrant.org/pdf_files/SC_stormwater_rpt.pdf

Wisconsin Administrative Code NR 528. 2012. Management of Accumulated Sediment from Storm Water Management Structures. Available at http://docs.legis.wisconsin.gov/code/admin_code/nr/500/528.pdf

4.11 Stormwater Wetlands

Stormwater 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 - 50-year, or flood control events) above the design storm (SWRv) storage.

Site Applicability		BMP Performance Summary		
Land Uses	Required Footprint	WQ Improvement: Moderate to High		
▪ Urban ▪ Suburban ▪ Rural	**Medium**	TSS[1]	Total N[1]	Bacteria[1]
		70-80%	30-35%	70%

Construction Costs	Maintenance Burden	Runoff Reductions	
		Rate	Volume
Moderate	Moderate	High	High
Maintenance Frequency:		*SWRv*	
Routine	Non-Routine	W-1	W-2
At least annually	Every 2 years	10% of *Sv*	10% of *Sv*

Advantages/Benefits	Disadvantages/Limitation
▪ High removal of typical stormwater pollutants ▪ Provides habitat for wildlife ▪ Attractive when integrated into site development ▪ Good for sites with high water table and/or poorly drained soils	▪ Requires large amount of flat land (3% of CDA) ▪ Must be properly designed, installed, and maintained to avoid nuisance problems ▪ Needs constant source of water ▪ Routine sediment cleanout may be needed ▪ Potential for thermal impacts downstream

Components	Design considerations
▪ Conveyance ▪ Forebay ▪ Deep ponding area ▪ High marsh and transition zones ▪ Micropool ▪ Spillway system(s)	▪ CDA must be large enough to sustain permanent water level ▪ Flow path through the wetland system should be at least 2L:1W ▪ 25% of pool depth should be 18-48 inches ▪ Water balance must be maintained

Maintenance Activities	
▪ Reinforce plantings as needed ▪ Remove accumulated sediments ▪ Remove invasive vegetation	▪ Thin/harvest vegetation every 2 years on embankments and access areas; elsewhere every 5-10 years

[1]*expected annual pollutant load removal*

Stormwater wetlands, sometimes called constructed wetlands, are shallow depressions that receive stormwater inputs for water quality treatment. 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. Wetlands include various design adaptations to allow them to be applied in specific settings. For example, some designs incorporate trees within the wetland area.

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 - 50-year or flood control events) to manage. Stormwater wetlands receive only 10% stormwater retention value and should be considered mainly for management of larger storm events. Stormwater wetlands have both community and environmental concerns (see Section 4.11.1 Stormwater Wetland Feasibility Criteria) that should be considered before choosing stormwater ponds for the appropriate stormwater practice on site.

Figure 0.52 Stormwater Wetland at Carolina Forest Recreation Center, Myrtle Beach
Photo: Kathryn Ellis

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 - 50-year, or flood control events) above the design storm (SWRv) storage. 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. Design variants include the following:

W-1 Shallow wetland

W-2 Extended detention shallow wetland

Several stormwater wetland design features are illustrated in Figure 0.51 through Figure 0.55.

Note: All of the pond performance criteria presented in Section 4.10 Ponds also apply to the design of stormwater wetlands. Additional criteria that govern the geometry and establishment of created wetlands are presented in this section.

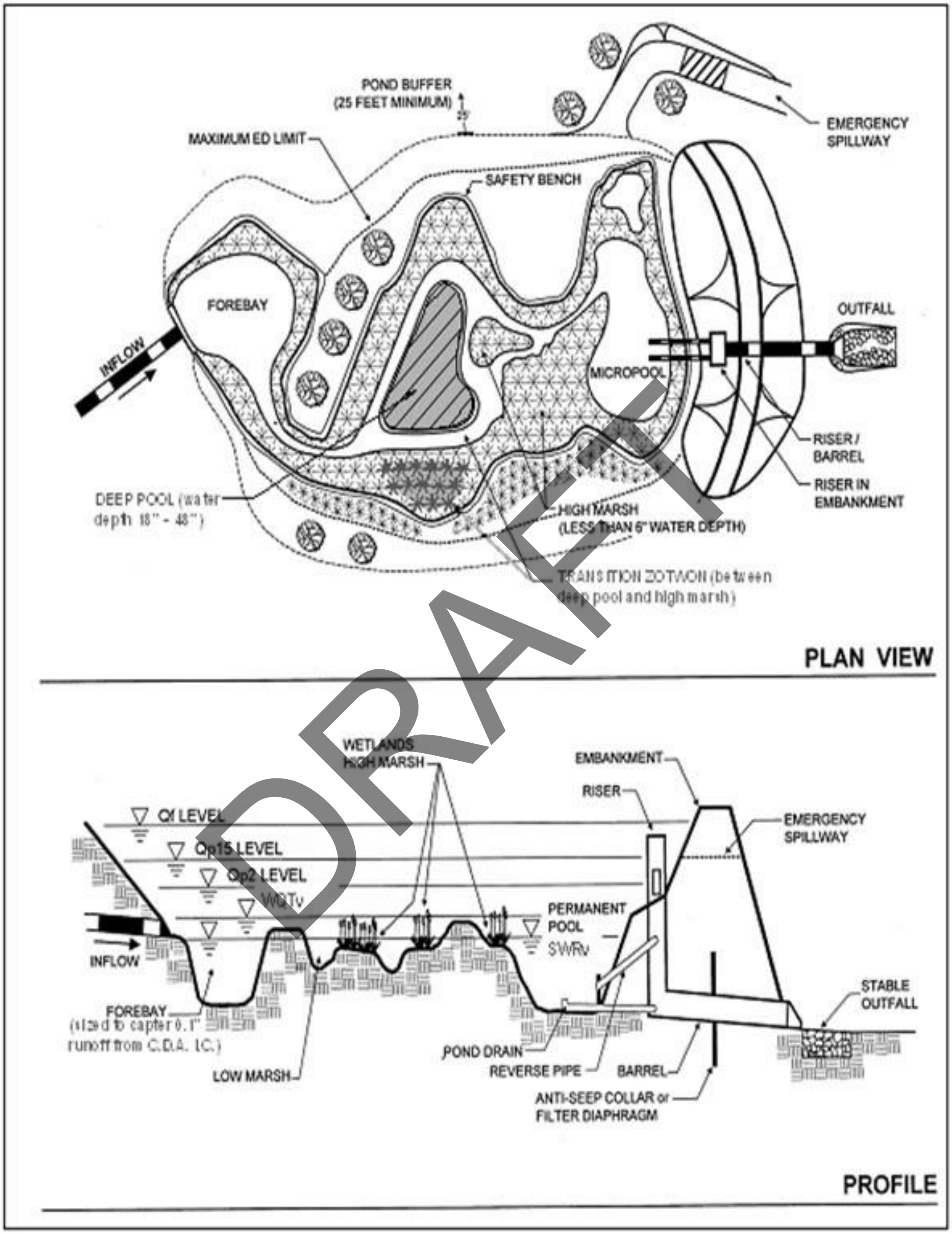

Figure 0.53 Example of extended detention shallow wetland.

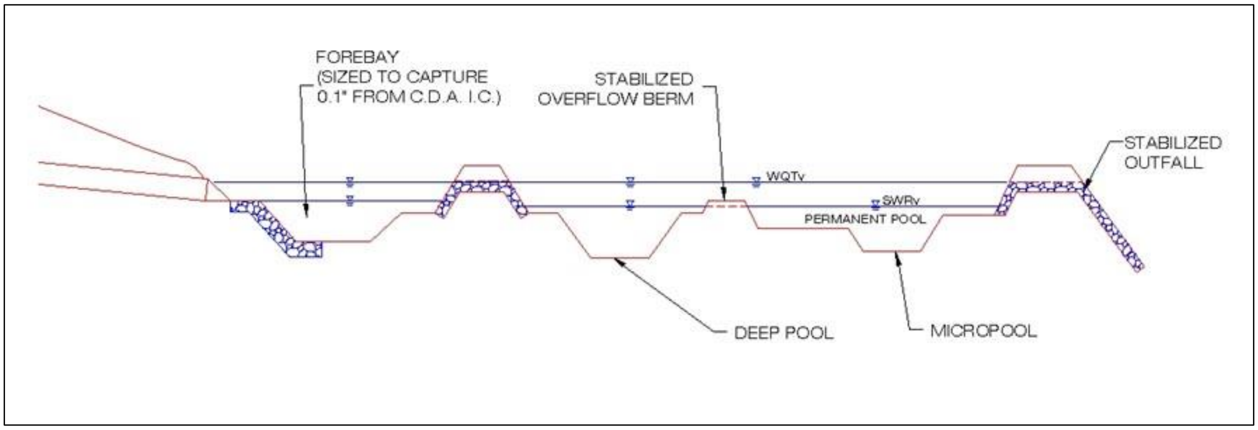

Figure 0.54 Cross section of a typical stormwater wetland.

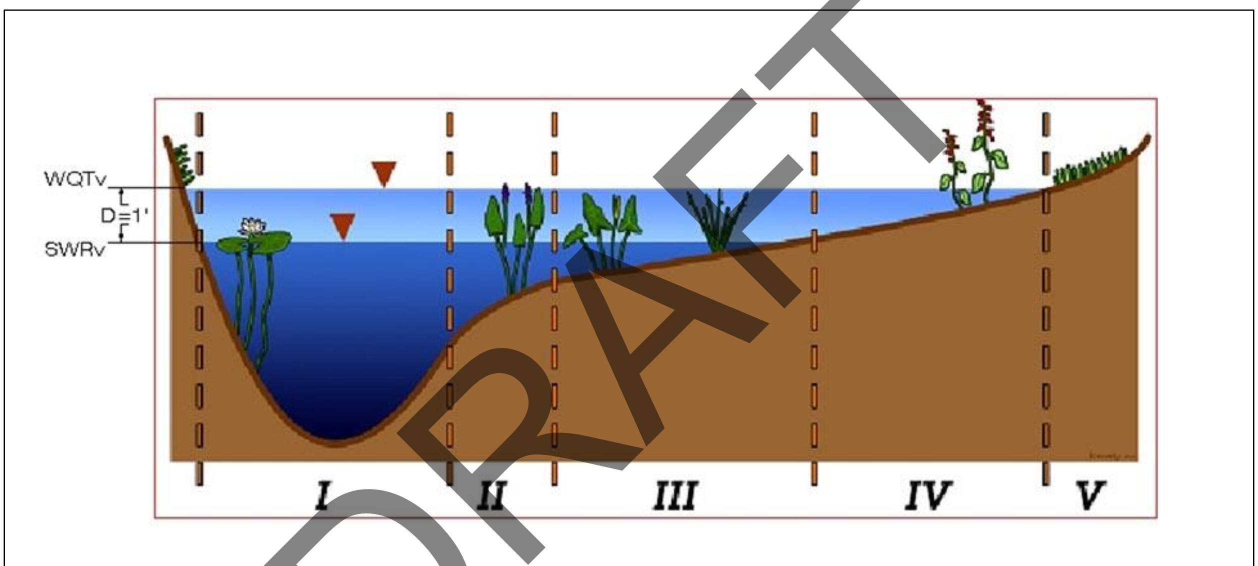

Figure 0.55 Interior wetland zones
(I) Deep Pool (depth -48 to -18 inches),
(II) Transition Zone (depth -18 to -6 inches),
(III and IV) High Marsh Zone (depth -6 to +6 inches),
(IV) Temporary Inundation Area, and
(V) Upper Bank

Adapted from Hunt et al., 2007

4.11.1 Stormwater Wetland Feasibility Criteria

Constructed wetland designs are subject to the following site constraints:

Adequate Water Balance. Stormwater 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 4.11.4 Stormwater Wetland Design Criteria.

Contributing Drainage Area. The CDA must be large enough to sustain a permanent water level within the stormwater wetland. If the only source of wetland hydrology is stormwater runoff, then several dozen acres of CDA are typically needed to maintain constant water elevations. Smaller CDAs are acceptable if the bottom of the stormwater 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% of the CDA, depending on the average depth of the wetland and the extent of its deep pool features.

Site Topography. Stormwater wetlands are best applied when the grade of contributing slopes is less than 8%.

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. A description of this practice is provided in Section 4.7 Open Channel Systems. For more detailed information on RSC systems, designers can consult Maryland's Anne Arundel County Design Specifications, available at http://www.aacounty.org/departments/public-works/wprp/watershed-assessment-and-planning/step-pool-conveyance-systems/index.html

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 cannot flow via baseflow from stormwater wetlands to the traditional pavement base layer, existing structure foundations, or future foundations which may be built on adjacent properties. Setbacks to structures and property lines must be at least 10 feet and adequate waterproofing 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 0 Ponds).

Soils. Soil tests should be conducted to determine the saturated hydraulic conductivity and other subsurface properties of the soils underlying the proposed stormwater wetland. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Underlying soils of 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 0.50 in Section 4.10 Ponds).

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, but designers should check with their wetland regulatory authorities to ensure the status.

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.

Economic Considerations. If space is available, wetlands can be a very cost-effective stormwater practice.

Community and Environmental Concerns. In addition to the community and environmental concerns that exist for stormwater ponds, the following must be addressed during design of stormwater wetlands:

- **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 may consider creating a wooded wetland (see Cappiella et al., 2006).
- **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 CDA. Deepwater zones serve to keep mosquito populations in check by providing habitat for fish and other pond life that prey on mosquito larvae. Few mosquito problems are reported for well-designed, properly sized, and frequently maintained 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).

4.11.2 Stormwater Wetland Conveyance Criteria

- The slope profile within individual stormwater 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 25-100-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 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.

4.11.3 Stormwater 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 3- to 6-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 4.10.3 Pond Pretreatment Criteria). The design of forebays should consider the possibility of heavy trash loads from public areas.

4.11.4 Stormwater 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. Stormwater 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. Stormwater 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% 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% of the total volume stored by the stormwater wetland, and its maximum water surface elevation shall not extend more than 3 feet above the normal pool.

Deep Pools. Approximately 25% of the stormwater 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% of the stormwater 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 stormwater 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 CDA served by these "closer" inlets must constitute no more than 20% of the total CDA.

Side Slopes. Side slopes for the stormwater 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.

Stormwater Wetland Material Specifications. Stormwater wetlands are generally constructed with materials obtained on site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and geotextile fabric for lining banks or berms. Plant stock should be nursery grown, unless otherwise approved (e.g. by the local regulatory authority), 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 during the local plan review.

Stormwater Wetland Sizing. Stormwater wetlands can be designed to capture and treat the remaining stormwater discharged from upstream practices from the design storm (SWRv). Additionally, stormwater wetlands can be sized to control peak flow rates from the 2- 50-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 2.10 Hydrology Methods for a summary of acceptable hydrologic 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 NRCS CN that reflects the volume reduction of upland practices to compute the 2- 50-year frequency storm event that must be treated by the stormwater 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 0.30). The total Sv cannot exceed the SWRv.

Equation 0.30 Stormwater Wetland Storage Volume

$$Sv = Stormwater\ wetland\ permanent\ pool\ volume$$

Sizing for Minimum Pool Depth. Initially, it is recommended that there be no minimum CDA 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 4.10 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 0.31 (Hunt et al., 2007), to assure the deep pools will not go completely dry during a 30-day summer drought.

Equation 0.31 Water Balance for Acceptable Water Depth in a Stormwater Wetland

$$DP = \left(RF_m \times EF \times \frac{WS}{WL}\right) - (ET - INF - RES)$$

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 stormwater 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 0.31, 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 0.32):

Equation 0.32 Minimum Depth of the Permanent Pool

$$DP = RF_m - ET - INF - RES = 21.2$$

where:

DP	=	depth of pool (in.)
RF_m	=	monthly rainfall during drought (in.)
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.)

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 4.11.4 Stormwater Wetland Design Criteria).

4.11.5 Stormwater 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 stormwater wetland facility and establishing vigorous plant cover.

Stage 1 Construction Sequence: Wetland Facility Construction.

Step 1: **Stabilize Contributing Drainage Area.** Stormwater wetlands should only be constructed after the CDA to the wetland is completely stabilized. If the proposed stormwater 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 ensure they conform to design specifications and prepare any staging areas.

Step 3: **Clear and Strip. Bring the project area** to the desired subgrade.

Step 4: **Install Soil Erosion and Sediment Control Measures** prior to construction, including sediment basins and stormwater diversion practices. All areas surrounding the stormwater 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 stormwater wetland. During construction, the stormwater wetland must be separated from the CDA so that no sediment flows into the wetland areas. In some cases, a phased or staged soil erosion and sediment control plan may be necessary to divert flow around the stormwater wetland area until installation and stabilization are complete.

Step 5: **Excavate the Core Trench for the Embankment and Install the Spillway Pipe.**

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 compact them 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 stormwater 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 the stormwater 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 stormwater wetland. The importance of soil amendments in excavated stormwater wetlands cannot be over-emphasized; poor survival and future wetland coverage are likely if soil amendments are not added. The planting soil should be a high organic content loam or sandy loam, placed by mechanical methods, and spread by hand. Planting soil depth should be at least 4 inches for shallow wetlands. No machinery should be allowed to traverse over the planting soil during or after construction. Planting soil should be tamped as directed in the design specifications, but it should not be overly compacted. After the planting soil is placed, it should be saturated and allowed to settle for at least one week prior to installation of plant materials.

Step 10: **Construct the Emergency Spillway** in cut or structurally stabilized soils.

Step 11: **Install Outlet Pipes.** The installation of outlet pipes must include a downstream riprap 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 Stormwater 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:

- Where the inundation zones are located in and around the stormwater 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 stormwater wetland.

Step 14: **Open Up the Stormwater Wetland Connection.** Once the final grades are attained, the pond and/or CDA connection should be opened to allow the wetland cell to fill up to the normal pool elevation. Gradually inundate the stormwater wetland to avoid 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 stormwater 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.** Two 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 can decrease the chance of survival, 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.

Step 17: **Install Goose Protection to Protect Newly Planted or Newly Growing Vegetation.** This is particularly critical for newly established emergent and herbaceous plants, as predation by Canada geese can quickly decimate wetland vegetation. Goose protection can consist of netting, webbing, or string installed in a crisscross pattern over the surface area of the stormwater wetland, above the level of the emergent plants.

Step 18: **Plant the Stormwater 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 stormwater 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)

Construction inspection checklist for Stormwater Wetlands can be found in Appendix E Construction Inspection Checklists.

4.11.6 Stormwater Wetland Landscaping Criteria

An initial stormwater 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 stormwater 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 0.54 provides a list of common native shrub and tree species and Table 0.55 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. 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 (*Typha latifolia*), common reed (*Phragmites australis*), and purple loosestrife (*Lythrum salicaria*) must not be planted.
- **Match Plants to Inundation Zones.** The various plant species shown in Table 0.54 and Table 0.55 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

  Zone 4 +12 inches to +36 inches above the normal pool elevation (i.e., above ED Zone)

  Note: The Low Marsh Zone (-6 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 stormwater wetland, five to seven species of emergent wetland plants should be planted, using at least four emergent species designated as aggressive colonizers (shown in bold in Table 0.55). No more than 25% of the high marsh wetland surface area needs to be planted. If the appropriate planting depths are achieved, the entire stormwater wetland should be colonized within 3 years. Individual plants should be planted 18 inches on center within each single species "cluster."
- **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 0.54 above presents some recommended tree and shrub species 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 6 to 9 months of lead time may be needed to fill orders for wetland plant stock from aquatic plant nurseries. Consult local regulatory authorities for information on area suppliers.

Table 0.54 Popular, Versatile, and Available Native Trees and Shrubs for Stormwater 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 to -12 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 to +36 inches; above ED zone
Source: Virginia DCR Stormwater Design Specification No. 13: Constructed Wetlands Version 1.8. 2010.

Table 0.55 Popular, Versatile, and Available Native Emergent and Submergent Vegetation for Stormwater Wetlands

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Arrow Arum *(Peltandra virginica)*	2	Emergent	Up to 1 ft	High; berries are eaten by wood ducks	Full sun to partial shade
Broad-Leaf Arrowhead (Duck Potato) *(Saggitaria latifolia)*	2	Emergent	Up to 1 ft	Moderate; tubers and seeds eaten by ducks	Aggressive colonizer

Plant	Zone[1]	Form	Inundation Tolerance	Wildlife Value	Notes
Blueflag Iris* *(Iris versicolor)*	2, 3	Emergent	Up to 6 in.	Limited	Full sun (to flower) to partial shade
Broomsedge *(Andropogon virginianus)*	2, 3	Perimeter	Up to 3 in.	High; songbirds and browsers; winter food and cover	Tolerant of fluctuating water levels and partial shade
Bulltongue Arrowhead *(Sagittaria lancifolia)*	2, 3	Emergent	0 to 24 in.	Waterfowl, small mammals	Full sun to partial shade
Burreed *(Sparganium americanum)*	2, 3	Emergent	0 to 6 in.	Waterfowl, small mammals	Full sun to partial shade
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	Submergen t / 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	Submergen t	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 Bulrush *(Scirpus cyperinus)*	3, 4	Emergent	Yes	High: waterfowl, small mammals	Fresh tidal and non-tidal, swamps, forested wetlands, meadows, ditches

Aggressive colonizers are shown in bold type
[1] Zone 1: -6 to -12 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 to +36 inches; above ED zone
*****Not a major colonizer, but adds color
Source: Virginia DCR Stormwater Design Specification No. 13: Constructed Wetlands Version 1.8. 2010.

4.11.7 Stormwater Wetland Maintenance Criteria

Successful establishment of constructed wetland areas requires that the following tasks be undertaken in the first 2 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 0.5 inch of rainfall.
- **Spot Reseeding.** Inspections should include looking for bare or eroding areas in the CDA or around the wetland buffer and make sure they are immediately stabilized with grass cover.
- **Watering.** Trees planted in the buffer and on wetland islands and peninsulas need watering during the first growing season. In general, consider watering every 3 days for first month, and then weekly during the first growing season (April through October), depending on rainfall.
- **Reinforcement Plantings.** Regardless of the care taken during the initial planting of the stormwater wetland and buffer, it is probable that some areas will remain unvegetated and some species will not survive. Poor survival can result from many unforeseen factors, such as predation, poor quality plant stock, water level changes, and 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 stormwater wetland that fail to fill in or survive. If a minimum coverage of 50% is not achieved in the planted wetland zones after the second growing season, 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 stormwater 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 stormwater wetland. As a general rule, control of undesirable invasive species (e.g., cattails and Phragmites) should commence when their coverage exceeds more than 15% of a wetland cell area. Although the application of herbicides is not recommended, some types (e.g., Glyphosate) have been used to control cattails with some success. Extended periods of dewatering may also work, since early manual removal provides only short-term relief from invasive species. While it is difficult to exclude invasive species completely from stormwater wetlands, their ability to take over the entire wetland can be reduced if the designer creates a wide range of depth zones and a complex internal structure within the wetland.

- For more information on invasive plants, consult the South Carolina Exotic Pest Plant Council. Resources are available online at http://www.se-eppc.org/southcarolina/invasivePlants.cfm.
- For more information related to chemical control methods for aquatic plants, please review the fact sheet "Aquatic Weed Control Overview" provided by Clemson's Cooperative Extension Service and available online at http://www.clemson.edu/extension/hgic/plants/other/landscaping/hgic1714.html.

Thinning or harvesting of excess forest growth may be periodically needed to guide the forested stormwater 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 stormwater 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 4.10.7 Pond Maintenance Criteria for additional maintenance responsibilities associated with stormwater wetlands. Ideally, maintenance of constructed wetlands should be driven by annual inspections by a qualified professional that evaluates the condition and performance of the stormwater wetland. Based on inspection results, specific maintenance tasks will be triggered.

Maintenance inspection checklist for stormwater wetlands and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

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 the *<local jurisdiction>* 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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 local, state, and federal law.

4.11.8 Stormwater Wetland Stormwater Compliance Calculations

Stormwater wetlands receive 10% retention value and are an accepted total suspended solids (TSS) treatment practice for the storage volume (Sv) provided by the BMP (Table 0.56).

Table 0.56 Stormwater Wetland Retention Value and Pollutant Removal

Retention Value	$= 0.1 \times Sv$
Accepted TSS Treatment Practice	Yes

The retention achieved by stormwater wetlands 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 through the 100-year storm events. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN 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.

4.11.9 References

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

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.

4.12 Tree Planting and Preservation

<table>
<tr><th colspan="10">Tree Planting and Preservation</th></tr>
<tr><td colspan="10">Definition: Existing trees can be preserved or new trees can be planted to reduce stormwater runoff.</td></tr>
<tr><td colspan="2">Site Applicability</td><td colspan="8">BMP Performance Summary</td></tr>
<tr><td>Land Uses</td><td>Required Footprint</td><td colspan="8">WQ Improvement: Moderate to High</td></tr>
<tr><td rowspan="3">▪ Urban
▪ Suburban
▪ Rural</td><td rowspan="3">Small</td><td colspan="3">TSS[1]</td><td colspan="2">Total N[1]</td><td colspan="3">Bacteria[1]</td></tr>
<tr><td colspan="3">N/A</td><td colspan="2">25-45%</td><td colspan="3">N/A</td></tr>
<tr><td colspan="8">Runoff Reductions</td></tr>
<tr><td>Construction Costs</td><td>Maintenance Burden</td><td colspan="4">Rate</td><td colspan="4">Volume</td></tr>
<tr><td>Low</td><td>Low</td><td colspan="4">Moderate</td><td colspan="4">Low</td></tr>
<tr><td colspan="2">Maintenance Frequency:</td><td colspan="8">SWRv*</td></tr>
<tr><td>Routine</td><td>Non-Routine</td><td>T-1 Small</td><td colspan="2">T-1 Large</td><td colspan="2">T-2 Small</td><td colspan="2">T-2 Large</td><td>T-2 Special</td></tr>
<tr><td>At least annually</td><td>Every 10-15 years</td><td>5 ft³</td><td colspan="2">10 ft³</td><td colspan="2">10 ft³</td><td colspan="2">20 ft³</td><td>40 ft³</td></tr>
<tr><td colspan="2">Advantages/Benefits</td><td colspan="8">Disadvantages/Limitation</td></tr>
<tr><td colspan="2">▪ High community acceptance
▪ Relatively low maintenance requirements
▪ Increases property value
▪ Easily incorporated with other practices
▪ Excellent for soils</td><td colspan="8">▪ Preserved trees must be protected during construction
▪ Must be within LOD
▪ Must maintain tree health</td></tr>
<tr><td colspan="2">Components</td><td colspan="8">Design considerations</td></tr>
<tr><td colspan="2">▪ Inventory of existing trees
▪ Identification of trees to preserve or plant
▪ Preference for Special/Heritage trees
▪ Average tree spread</td><td colspan="8">▪ Inventory of existing trees
▪ Identification of trees to preserve or plant
▪ Preference for Special/Heritage trees
▪ Slope-steep slopes must be terraced/benched
▪ Maintenance access</td></tr>
<tr><td colspan="10">Maintenance Activities</td></tr>
<tr><td colspan="2">▪ If staked during establishment, remove stakes within 1 year of planting</td><td colspan="8">▪ Maintain appropriate mulch cover
▪ Ensure tree health</td></tr>
</table>

[1]*expected annual pollutant load removal*

**per Planted/Preserved Tree*

Easily combined with other practices, tree planting and preservation provide stormwater interception, beauty, and shade, thereby increasing aesthetics and property values. See Figure 0.56

Figure 0.56 Tree Planting and Preservation in Bioretention
Photo: Center for Watershed Protection

Definition. Existing trees can be preserved or new trees can be planted to reduce stormwater runoff. The design includes the following:

T-1 Tree planting

T-2 Tree preservation

Tree canopy can intercept a significant amount of rainfall before it becomes runoff, particularly if the tree canopy covers impervious surfaces, as in the case of street trees. Through the processes of evapotranspiration and nutrient uptake, trees—even when 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. Note that retention value is available for preserved trees only when they are within the limits of disturbance of a project. Preserved trees outside of the limits of disturbance may offer an opportunity for additional retention when they constitute an area of natural cover and stormwater is conveyed to that area.

4.12.1 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. An inventory of existing trees and forested areas at the development site must be conducted before any site design, clearing, or construction takes place, as specified by the DDOT UFD. The inventory must be conducted by one of the following landscape professionals:

- South Carolina Licensed Forester
- South Carolina Licensed Tree Expert
- South Carolina Experienced Forester
- South Carolina Licensed Landscape Architect
- International Society of Arboriculture (ISA) Certified Arborist

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. Preserved trees fall into three categories of retention value: tree species with an average mature spread less than or equal to 40 feet ("small" trees) receive 10 cubic feet of retention value; trees species with an average mature spread greater than or equal to 40 feet ("large" trees) receive 20 cubic feet of retention value; and Special Trees/Heritage Trees receive 40 cubic feet of retention value, regardless of mature spread size. Additional selection criteria may include tree species, size, condition, and location (see Table 0.57).

Table 0.57 Selecting Priority Trees and Forests for Preservation

Selection Criteria	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 (DBH) or other size measurement ▪ Trees designated as national, state, or local champions ▪ Contiguous forest stands
Condition	▪ Healthy trees that are structurally sound in "fair" or better condition ▪ High quality forest stands with high forest structural diversity

Selection Criteria	Examples of Priority Tree and Forests to Conserve
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 is 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 landscape professional from the above list, and in general is equal to 1.5 feet of tree protection (radius of circle) for every 1 inch in tree diameter. For example, a 10-inch diameter tree would have a CRZ radius extending 15 feet from the tree. The barriers must be maintained and enforced throughout the construction process. Tree protection barriers include highly visible, well-anchored temporary protection devices, such as 6-foot-tall chain link or 4-foot wooden snow fencing.

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.

4.12.2 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. Planted trees fall into two categories of retention value: tree species with an average mature spread less than or equal to 40 feet ("small" trees) receive 5 cubic feet of retention value and trees species with an average mature spread greater than or equal to 40 feet ("large" trees) receive 10 cubic feet of retention value. Trees to be planted must have a minimum caliper size of 1.5 inches.

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 large 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 large tree. Rootable soil volume must be within 3 feet of the surface.

Smaller trees with an average mature spread of less than or equal to 40 feet must have a minimum of 600 cubic feet of rootable soil volume. In planting arrangements that permit shared rooting space amongst multiple trees, a minimum of 400 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 0.58 presents methods for addressing common constraints to urban tree planting.

Table 0.58 Methods for Addressing Urban Planting Constraints

Potential Impact	Potential Resolution
Limited Soil Volume	▪ Provide 1,500 cubic feet of rootable soil volume per large tree (greater than or equal to 40-foot spread) and 600 cubic feet of rootable soil volume per small tree (less than or equal to 40-foot spread). This soil must be within 3 feet of the surface. ▪ 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. A minimum of 400 cubic feet of rootable soil volume must be provided for each small tree in shared rooting arrangements.
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 runoff	▪ Select species that are tolerant of specific pollutants, such as salt and metals.

Potential Impact	Potential Resolution
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 soil volume for healthy tree growth. Usable 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.

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 0.59).

Table 0.59 Tree Planting Techniques

Plant Material	Planting Technique	Planting Season
Bare root	Hand plant	Spring or fall when tree is dormant
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. Trees planted too deeply have buried root collars, and are weakened, stressed, and predisposed to pests and disease. Trees planted too deeply can also form adventitious roots (roots that form from non-root tissue) near the soil surface in an attempt to compensate for the lack of available oxygen to buried roots. Adventitious roots are not usually large enough to provide support for a large tree and may eventually lead to collapse. 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.

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 0.57. Trees must be watered well after planting.

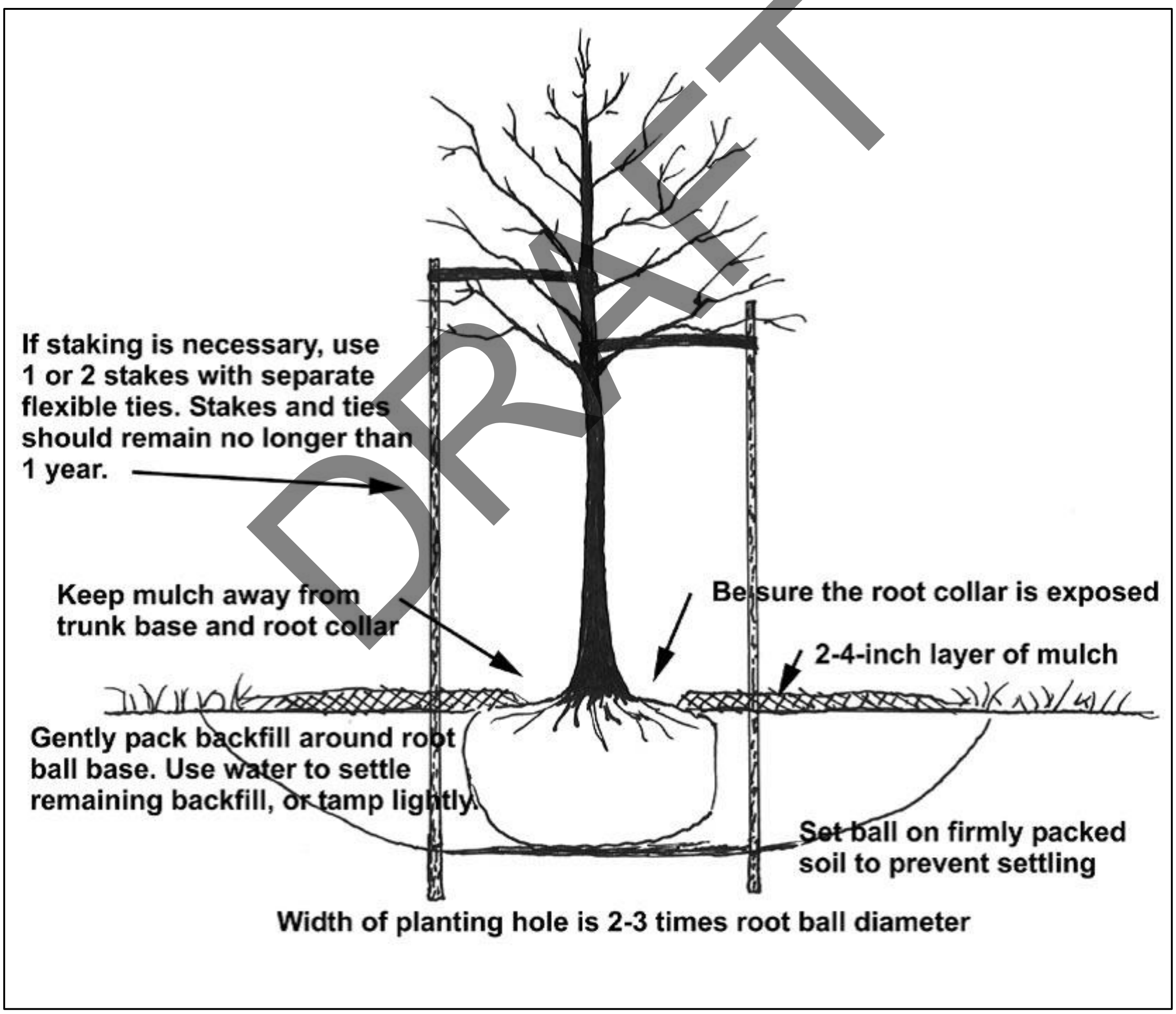

Figure 0.57 Tree planting guidelines.
Adapted from Flott, 2004 and ISA, 2003b

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. 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.

Trees will add stability to slopes because of their deep roots, provided they are not planted by digging rows of pits across a slope. 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 3H:1V involve creating a level planting space on the slope (see Figure 0.58). A terrace can be dug into the slope in the shape of a step by cutting into the existing slope and using the excavated soil as fill to create the step area. 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.

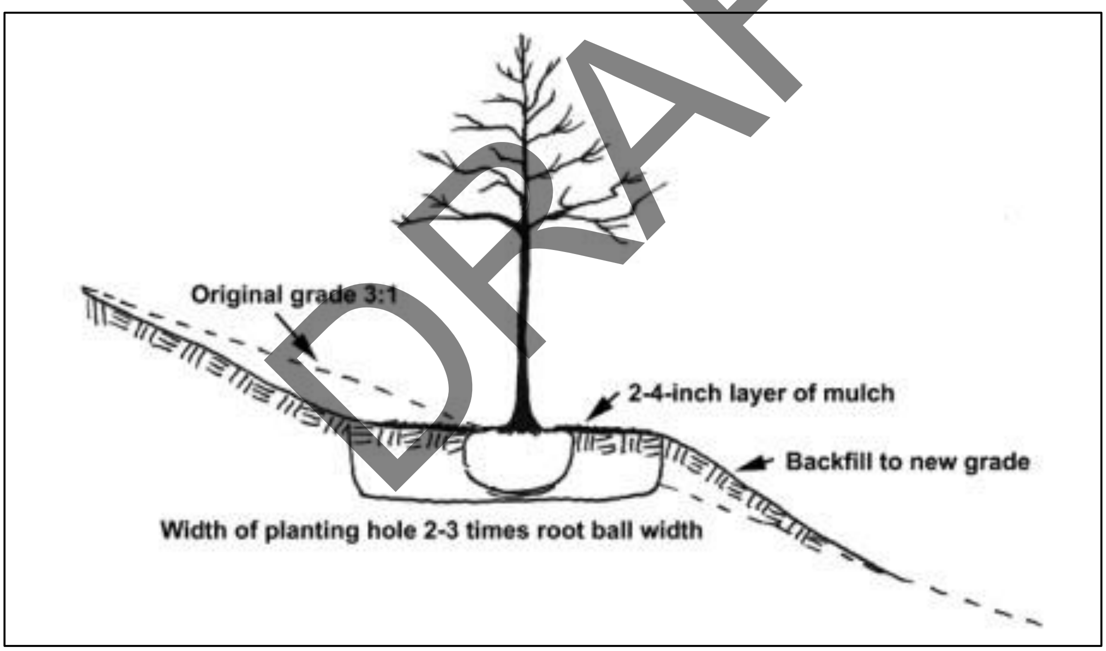

Figure 0.58 Trees planted on steep slopes require a constructed level planting surface.

Post-Planting Tree Protection.

Mulching: Once the tree has been properly planted, 2 to 4 inches (maximum) of organic mulch must be spread over the soil surface out to the drip line (the outermost circumference of the tree canopy) 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

If planting a cluster of trees, mulch the entire planting area, ensuring a 2- to 3-inch wide mulch free area at the base of each tree.

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. 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. 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.

Staking: 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. Staking for support may be necessary only for top-heavy trees or at sites where vandalism or windy exposure are a concern.

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.

4.12.3 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 the 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.

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.

Construction inspection checklist for tree planting and preservation can be found in Appendix E Construction Inspection Checklists.

4.12.4 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 3 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. 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 encourage roots to grow at the surface. Soaker hoses and drip irrigation work best for deep watering of trees. It is recommended 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. As the tree grows, lower branches may be pruned to provide clearance above the ground, or to remove dead or damaged limbs.

Maintenance inspection checklist for tree planting and preservation and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

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 the *<local jurisdiction>* 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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 local, state, and federal law.

4.12.5 Tree Stormwater Compliance Calculations

Trees receive retention value credit, 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 tree of similar mature spread no longer than 6 months from time of death in an appropriate location.

Preserved trees located within a site's limits of disturbance (LOD) that meet the requirements described above receive a retention value of 10, 20, or 40 cubic feet each, depending upon the size of the mature spread of the tree and whether the tree is designated as Special or Heritage. Note: To receive the preserved tree retention value, trees must be left undisturbed in their original location. Trees that are removed and replanted are not considered preserved trees.

Planted trees that meet the requirements described above receive a retention value of 5 or 10 cubic feet each, depending upon the size of the mature spread of the tree. Note: Trees planted as part of another BMP, such as a bioretention area, also receive the 5 or 10 cubic foot retention value.

Retention values are shown in T-1 and Table 0.60 below.

Table 0.60 T-1 Planted Tree Retention Value and Pollutant Removal

	Small Trees (average spread ≤ 40 feet)	Large Trees (average spread > 40 feet)
Retention Value	= 5 ft^3 (37.5 gallons)	= 10 ft^3 (75 gallons)
Accepted TSS Treatment Practice	No	No

Table 0.61 T-2 Preserved Tree Retention Value and Pollutant Removal

	Small Trees (average spread ≤ 40 feet)	Large Trees (average spread > 40 feet)	Special/Heritage Trees (> 44-inch circumference)
Retention Value	= 10 ft^3 (75 gallons)	= 20 ft^3 (150 gallons)	= 40 ft^3 (300 gallons)
Accepted TSS Treatment Practice	No	No	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 - 50-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a reduced NRCS CN for the site or SDA. The reduced NRCS CN 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.

4.12.6 References

Alliance for the Chesapeake Bay (ACB). 2000. Pennsylvania Stream ReLeaf forest buffer toolkit. Harrisburg, PA: Pennsylvania Department of Environmental Protection.

Arendt, R. G. 1996. Conservation design for subdivisions. A practical guide to creating open space networks. Washington, DC: Island Press. 184 p.

Bassuk, N.; Curtis, D. F.; Marranca, B. Z.; Neal, B. 2003. Recommended urban trees: site assessment and tree selection for stress tolerance. Ithaca, NY: Cornell University, Urban Horticulture Institute. 127 p. http://www.hort.cornell.edu/uhi/ (Accessed December 28, 2005).

Buckstrup, M.; Bassuk, N. 2000. Transplanting success of balled-and-burlapped versus bare-root trees in the urban landscape. Journal of Arboriculture 26(6): 298-308.

Cappiella, K.; Schueler, T.; Wright, T. 2006. Urban Watershed Forestry Manual. United States Department of Agriculture Forest Service. Newtown Square, PA.

Caraco, D. 2000. Keeping soil in its place. In: Schueler, T.; Holland, H., eds. The practice of watershed protection. Ellicott City, MD; 323-328.

Center for Watershed Protection. 1998. Better site design: a handbook for changing development rules in your community. Ellicott City, MD. 174 p.

Cornell University. 2004. Conducting a street tree inventory. Ithaca, NY: Cornell University, Department of Horticulture. http://www.hort.cornell.edu/commfor/inventory/index.html (Accessed December 28, 2005).

Doherty, K.; Bloniarz, D.; Ryan, H. 2003. Positively the pits: successful strategies for sustainable streetscapes. Tree Care Industry 14(11): 34-42. http://www.umass.edu/urbantree/publications/pits.pdf (Accessed 2006).

Flott, J. 2004. Proper planting begins below ground. TreeLink 19: 1-4.

Georgia Forestry Commission (GFC). 2002. Community tree planting and establishment guidelines. Dry Branch, GA.

Gilman, E. F. 1997. Trees for urban and suburban landscapes. Albany, NY: Delmar Publishers.

Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. 122 p.

Hairston-Strang, A. 2005. Riparian forest buffer design and maintenance. Annapolis: Maryland Department of Natural Resources. http://dnr.maryland.gov/forests/Pages/publications.aspx

Head, C.; Robinson, F.; O'Brien, M. 2001. Best management practices for community trees: a guide to tree conservation in Athens-Clarke County, Georgia. Athens, GA: Athens-Clarke County Unified Government.

International Society of Arboriculture (ISA). 2005. Avoiding excessive soil over the root systems of trees. Arborist News, April.

International Society of Arboriculture (ISA). 2003a. Proper mulching techniques. Champaign, IL: International Society of Arboriculture. http://treesaregood.org/portals/0/docs/treecare/ProperMulching.pdf (Accessed 2006).

International Society of Arboriculture (ISA). 2003b. New tree planting. Champaign, IL: International Society of Arboriculture.

Johnson, G. R. 2005. Protecting trees from construction damage: a homeowner's guide. St. Paul, MN: Regents of the University of Minnesota. http://www.extension.umn.edu/garden/yard-garden/trees-shrubs/protecting-trees-from-construction-damage/ (Accessed December 28, 2005).

Kochanoff, S., 2002. Trees vs. power lines: priorities and implications in Nova Scotia. Presented at the 5th Annual Canadian Urban Forest Conference. Markham, ON.

Maryland National Capital Parks and Planning Commission. 1992. Trees. Approved Technical Manual. Maryland National Capital Parks and Planning Commission, Montgomery County, MD. 144 p. http://www.montgomeryplanning.org/environment/forest/trees/toc_trees.shtm

Meyer, D. 1993. Tree shelters for seedling protection and increased growth. Forestry Facts 59. Madison, WI: University of Wisconsin Extension.

Minnesota Department of Natural Resources. 2000. Conserving wooded areas in developing communities. BMPs in Minnesota. Minnesota Department of Natural Resources, St. Paul, MN. 113 p. http://www.dnr.state.mn.us/forestry/urban/bmps.html (Accessed December 28, 2005).

Morrow, S.; Smolen, M.; Stiegler, J.; Cole, J. 2002. Using vegetation for erosion control. Landscape Architect 18(11): 54-57.

Nebraska Forest Service. 2004. Tree selection and placement. Storm Damage Bulletin No. 7. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1068&context=nebforestpubs

Palone, R. S.; Todd, A. H., eds. 1998. Chesapeake Bay riparian handbook: a guide for establishing and maintaining riparian forest buffers. NA-TP-02-97. Radnor, PA: USDA Forest Service, Northeastern Area State and Private Forestry.

Pennsylvania State University. 1999. A guide to preserving trees in development projects. University Park, PA: Penn State College of Agricultural Sciences, Cooperative Extension. 27 p.

Pennsylvania State University (PSU). 1997. Questions about trees and utilities. Forestry Fact Sheet #7. University Park: Pennsylvania State University, College of Agricultural Sciences.

Petit, J.; Bassert, D. L.; Kollin, C. 1995. Building greener neighborhoods. Trees as part of the plan. Washington, DC: American Forests and the National Association of Homebuilders.

Schueler, T. R. 1995. Site planning for urban stream protection. Ellicott City, MD: Center for Watershed Protection. 232 p.

Schueler, T.; Brown, K. 2004. Urban stream repair practices. Version 1.0. Manual 4 of the Urban Subwatershed Restoration Manual Series. Ellicott City, MD: Center for Watershed Protection.

Sweeney, B. W. 1993. Effects of streamside vegetation on macroinvertebrate communities of White Clay Creek in Eastern North America. In: Proceedings of the Academy of Natural Sciences of Philadelphia. Philadelphia, PA; 291-340.

Tree Care Industry Association (TCIA). 2004. ANSI A300 Standards for tree care operations. Manchester, NH; https://www.tcia.org/TCIA/BUSINESS/ANSI_A300_Standards_/TCIA/BUSINESS/A300_Standards/A300_Standards.aspx?hkey=202ff566-4364-4686-b7c1-2a365af59669 (Accessed 2005).

Trowbridge, P.; Bassuk, N. 2004. Trees in the urban landscape: site assessment, design, and installation. Hoboken, NJ: John Wiley & Sons, Inc.

USDA Forest Service. 1998. Volunteer training manual. Amherst, MA: Northeast Center for Urban and Community Forestry. 86 p. http://www.umass.edu/urbantree/volmanual.pdf (Accessed December 28, 2005).

Washington State Aquatic Habitat Guidelines Program (WSAHGP). 2002. Integrated streambank protection guidelines. Olympia, WA. Unpaginated.

4.13 Proprietary Practices

<table>
<tr><th colspan="6">Proprietary Practices</th></tr>
<tr><td colspan="6">Definition: 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. Performance varies based on manufacturer's design.</td></tr>
<tr><th colspan="2">Site Applicability</th><th colspan="4">BMP Performance Summary</th></tr>
<tr><th>Land Uses</th><th>Required Footprint</th><th colspan="4">WQ Improvement: Moderate to High</th></tr>
<tr><td rowspan="2">▪ Urban
▪ Suburban
▪ Rural</td><td rowspan="2">Small</td><th>TSS[1]</th><th colspan="2">Total N[1]</th><th>Bacteria[1]</th></tr>
<tr><td>Varies*</td><td colspan="2">Varies*</td><td>Varies*</td></tr>
<tr><td colspan="2"></td><th colspan="4">Runoff Reductions</th></tr>
<tr><th>Construction Costs</th><th>Maintenance Burden</th><th colspan="2">Rate</th><th colspan="2">Volume</th></tr>
<tr><td>Moderate</td><td>Moderate</td><td colspan="2">Varies*</td><td colspan="2">Varies*</td></tr>
<tr><th colspan="2">Maintenance Frequency:</th><th colspan="4">SWRv</th></tr>
<tr><th>Routine</th><th>Non-Routine</th><td colspan="4" rowspan="2">Refer to Device Manufacturers Specifications</td></tr>
<tr><td>At least annually</td><td>Variable</td></tr>
<tr><th colspan="2">Advantages/Benefits</th><th colspan="4">Disadvantages/Limitation</th></tr>
<tr><td colspan="2">▪ On- or off-line treatment
▪ Useful in challenging stormwater site designs
▪ Water quality treatment</td><td colspan="4">▪ Devices can be costly
▪ Must be approved by regulating authority
▪ Most devices do not provide retention</td></tr>
<tr><th colspan="2">Components</th><th colspan="4">Design considerations</th></tr>
<tr><td colspan="2">▪ Pretreatment
▪ Conveyance
▪ Bypass mechanism</td><td colspan="4">▪ Must safely overflow or bypass flow from 2 - 50-year design storms.
▪ Manufacturer's specifications
▪ Adequate maintenance access required</td></tr>
<tr><th colspan="6">Maintenance Activities</th></tr>
<tr><td colspan="2">▪ Based on manufacturer's specifications</td><td colspan="4">▪ Routine inspection for proper function</td></tr>
</table>

[1] *expected annual pollutant load removal*

**varies according to proprietary practice*

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. The design includes the following:

M-1 Proprietary practices

Proprietary practices may be used to achieve treatment compliance, provided they have been approved by the State and meet the performance criteria outlined in this specification. Historically, proprietary practices do not provide retention volume. A proprietary practice will not be valued for retention volume unless the practice can demonstrate the occurrence of retention processes.

4.13.1 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.

4.13.2 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 - 50-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.

4.13.3 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.

4.13.4 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 I Hydrology and Hydraulics Design Requirements.

Appendix K Proprietary Practices Approval Process includes details of the verification process and the required data submittals for determination of proprietary practice performance.

Adequate maintenance access must be provided for all proprietary practice systems. Access, with access steps, as applicable, must be provided for the inlet pipe, outflow structure, and over any other functional components.

4.13.5 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.

4.13.6 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.

Construction inspection checklist for generic structural BMPs can be found in Appendix E Construction Inspection Checklists.

4.13.7 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 *<Local jurisdiction>*.

Maintenance inspection checklist for generic structural BMPs and the Maintenance Service Completion Inspection form can be found in Appendix F Maintenance Inspection Checklists.

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 the *<local jurisdiction>* 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 in Appendix O, although variations will exist for scenarios where stormwater crosses property lines. The covenant is attached to the land and is to be recorded in the Register of Deeds in the County office. 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 local, state, and federal law.

4.13.8 Proprietary Practice Stormwater Compliance Calculations

Proprietary practices receive retention value when explicitly approved by the *<local jurisdiction>*. Pollutant removal (TSS EMC reduction) may be awarded for specific practices provided they meet the performance criteria outlined in Section 4.13.4 Proprietary Practice Design Criteria.

4.14 Conservation Area

A Conservation Area is where the user has the option to indicate whether a portion of the drainage basin is protected under a conservation easement or equivalent form of protection. There are four scenarios that could qualify for a conservation area credit. If a portion of the drainage basin is protected under one or more of the four scenarios, in the compliance calculator (Appendix H) check the appropriate box and the corresponding area input cell will unlock.

4.14.1 Scenario 1: Natural Conservation Area

Scenario 1 is applicable if a portion of the post-developed area is left in its natural condition and protected, in perpetuity, by a conservation easement or equivalent form of protection. If this scenario is applicable, subtract 100% of the protected natural area from the total site area when calculating the SWRv.

4.14.2 Scenario 2: Reforestation/Revegetation

Scenario 2 is applicable if a portion of the post-developed area employs site reforestation/revegetation and is protected, in perpetuity, by a conservation easement or equivalent form of protection. If this application is used alone, subtract 50% of the reforested/revegetated area from the total site area when calculating the SWRv.

4.14.3 Scenario 3: Soil Restoration

Scenario 3 is applicable if a portion of the post-developed area employs soil restoration and is protected, in perpetuity, by a conservation easement or equivalent form of protection. If this application is used alone, subtract 50% of the soil restoration area from the total site area when calculating the SWRv.

4.14.4 Scenario 4: Reforestation/Revegetation & Soil Restoration

Scenario 4 is applicable if the same portion of the post-developed area employs site reforestation/revegetation as well as soil restoration and is protected, in perpetuity, by a conservation easement or equivalent form of protection, subtract 100% of the acres of development with restored soils in a reforested and revegetated area from the total site area when calculating the SWRv.