3.0 Stormwater BMP Design

Maryland stormwater management requirements allow the use of a variety of stormwater BMPs to manage runoff to meet the minimum requirements for new development and redevelopment. This chapter presents specific performance criteria and design requirements for two types of stormwater BMPs: ESD practices and structural BMPs. Many of the stormwater BMPs include filters. A filter is comprised of multiple forms of media which vary depending on the type of BMP and potentially include: mulch, bioretention soil media, sand, pea gravel, gravel. The soils and groundwater conditions of the development site are a critical determining factor for BMP selection and shall be used to determine what type of filter is appropriate.

3.0.1 ESD Practices

ESD practices reduce the pollutants in runoff from small drainage areas through filtration and infiltration. ESD practices are limited to managing small runoff volumes and must be designed to bypass larger storm events. There are four categories of ESD practices:

1. **Non-structural Practices:** Non-structural practices allow for the disconnection of impervious area by combining grading and landscaping to divert runoff into vegetated areas and away from conventional storm drain systems.

2. **Alternative Surfaces:** Alternative surfaces such as permeable pavements and reinforced turf, replace impervious surfaces with pervious-like surfaces. A green roof is an alternative surface that filters stormwater runoff using a retained volume.

3. **Micro-Scale Practices.** Micro-scale practices are small filtering and infiltration practices. These practices use soil and/or stone media, and vegetation combined to provide water quality treatment, groundwater recharge, and channel protection through infiltration, filtration, evapotranspiration, rainwater harvesting, or a combination of these techniques.

4. **Open Channel Practices:** Open channel practices are linear conveyance systems that provide pollutant removal through filtering, sedimentation, biological uptake, and infiltration into the underlying soils

ESD practices are either area-based or volume based. When implementing area-based practices, the amount of impervious area on the development site that requires treatment is reduced. Area based practices include non-structural practices, alternative surfaces (except green roofs), and grass swales. Volume-based practices are designed to provide a treatment volume for the impervious area on the development site within the drainage area to the practice. Volume based practices include micro-scale practices, bio swales, and wet swales. Area-based practices must be designed to manage the full required stormwater management for the area they are treating. Volume-based practices, however, may be designed to provide all or a portion of the required management for their drainage area.

3.0.2 Structural Practices

Structural practices remove pollutants through retention and settling, extended detention, vegetative uptake, infiltration, and filtration. Structural practices are larger and broader in their application than ESD practices with no maximum limit on treatment volume or drainage area size. Because of their size, structural practices may have additional requirements for embankment freeboard, construction specifications, safety features, and maintenance. All structural practices, except grass swales, are volume-based practices. There are four categories of structural practices:

1. **Stormwater Ponds:** Stormwater ponds provide temporary or permanent storage of stormwater runoff to provide treatment and/or slowing or reducing the runoff discharge rate. Stormwater ponds can be designed with or without a permanent pool, as a combination of extended detention with a permanent pool, as a combination of extended detention without a permanent pool, or as a dry detention or dry extended detention practice.
2. **Stormwater Wetlands:** Stormwater wetlands are practices where shallow wetland areas are created to treat urban stormwater runoff. These practices incorporate small permanent pools to manage the water quality volume and may include extended detention storage to manage the channel protection volume. Like ponds, stormwater wetlands can be designed to provide detention for flood control.
3. **Stormwater Infiltration:** Stormwater infiltration practices capture and temporarily store stormwater runoff to promote infiltration into the soil. Like ponds, stormwater wetlands can be designed to provide extended detention and detention.
4. **Stormwater Filtering Practices:** Stormwater filtering practices are designed to capture and temporarily store stormwater runoff and pass it through a filter bed of sand, organic matter, soil, or other media. Filtered runoff is treated, and either returned to the conveyance system or held for infiltration into the soil.

3.0.3 Applicability and Limitations of BMPs for Managing Design Criteria

Water Quality Treatment (WQ_v) and Groundwater Recharge (Re_v): All ESD practices in this Manual can be used to provide water quality treatment (or WQ_v) for new development and redevelopment. With the exception of dry detention and dry extended detention ponds, all structural practices in this Manual can be used to meet the WQ_v requirements for redevelopment. To meet the Re_v requirement for new development and redevelopment, an ESD practice must provide infiltration.

Channel Protection (Cp_v): To meet the Cp_v, requirements for new development, a practice must store and slowly release the required amount of runoff from the 1-year storm (per adjusted values in Table 2.1). Most of the ESD practices (e.g., infiltration and micro-filtering systems) incorporate features that capture, store, and slowly release stormwater runoff. However, ESD practices are limited to providing a maximum of 8,000 ft^3 (4,000 ft^3 in Use Class III and IV watersheds) of treatment volume for meeting the Cp_v requirement. When the Cp_v requirement for the discharge point from the development site is greater than 8,000 ft^3 (4,000 ft^3 in Use Class III and IV watersheds), a structural practice shall be used. More information on whether an ESD practice or a structural BMP can be used to meet Cp_v and the limitations for each practice type is included in Table 3.1, Tables 3.2 and 3.3, and in each respective BMP section.

Flood Protection (q_p and q_f): ESD practices are not to be used for flood protection. To be used for flood protection, a structural practice must have a dedicated storage volume for attenuating stormwater runoff. To avoid clogging and erosion, structural filtering practices that use media (sand or bioretention soil mix) to filter stormwater runoff shall be designed in such a manner that the flood protection storm does not pass through the filter. Instead, the flood protection storage volume can be provided above the filter surface in addition to the required water quality surface storage. The applicability and design limitations of a practice to provide flood protection is indicated in Table 3.1 and Tables 3.2 and 3.3, and in each respective BMP section.

Table 3.1 Applicability and Limitations of BMPs for Managing Design Criteria

Criteria	Applicability and Limitations	
	ESD Practice	Structural Practice
Water Quality	Used to provide water quality treatment for new development and redevelopment	Only applicable for treating water quality for redevelopment
Groundwater Recharge	Applicable if BMP provides for seepage into ground	Applicable if BMP provides for seepage into ground Applicable for wet ponds, wet swales, stormwater wetlands where permanent pool is sustained by high groundwater table
Channel Protection	Used where the Cp_v requirement for the discharge point from the development site ≤ 8,000 ft^3 (4,000 ft^3 in cold water resource watersheds) For filtering practices, 75% of Cp_v runoff treatment volume is stored above the filter For dry wells, 100% of Cp_v runoff treatment volume is stored within the BMP (above surface and in media) For raingardens and infiltration	Used where the Cp_v requirement for the discharge point from the development site > 8,000 ft^3 (4,000 ft^3 in cold water resource watersheds) For extended detention ponds and wetland ponds, the extended detention storage volume is 62% of the Cp_v runoff treatment volume in all watersheds except Use Class III/IV and 56% in Use Class III/IV watersheds For infiltration practices, 100% of the Cp_v runoff treatment volume is stored within the BMP (above the

Criteria	Applicability and Limitations	
	ESD Practice	Structural Practice
	berms, 100% of Cp_v runoff treatment volume is stored above/upgrade of media	surface and in the media) For filtering practices, 75% of Cp_v runoff treatment volume is stored above the filter For submerged gravel wetlands, 100% of the Cp_v runoff treatment volume is stored above the surface and 100% of Cp_v runoff treatment volume is also stored in the media
Flood Protection	Not applicable ESD practices are designed to prevent storms greater than 1-year storm from flowing through the filter	Ponds are preferred practice For filtering practices, • Runoff volumes greater than runoff volume from 1-yr storm are prevented from flowing through the filter • q_f and/or q_p storage is provided above the WQ_v or Cp_v surface storage • WQ_v or Cp_v volume does not contribute to q_f or q_p management

Note: Runoff treatment volume = the volume of runoff being treated by the practice

Table 3.2 ESD Practices and Their Function

ESD Practices and Their Function					
	Is practice volume-based or area-based?	**Water Quality (WQ_v)**	**Recharge Volume (Re_v)[3]**	**Channel Protection Volume (Cp_v)**	**Flood Protection (q_p and q_f)**
Non-structural Practices					
Disconnection of Rooftop Runoff	area	yes	yes	no	no
Disconnection of Non-Rooftop Runoff	area	yes	yes	no	no
Sheetflow to Conservation Areas	area	yes	yes	no	no
Alternative Surfaces					
Permeable Pavement	area	yes	yes, if no underdrain	no	no
Reinforce Turf	area	yes	yes, if no underdrain	no	no
Green Roofs	volume	yes	no	yes	no
Micro-Scale Practices					
Rain Garden	volume	yes	yes	maybe[1]	no
Infiltration Berm	volume	yes	yes	maybe[1]	no
Rain barrels	volume	yes	maybe[2]	no	no
Micro-bioretention	volume	yes	yes, with storage below underdrain	yes	no
Landscape Infiltration	volume	yes	yes	yes	no
Dry Well	volume	yes	yes	yes	no
Pocket Submerged Gravel Wetland	volume	yes	yes, if no liner	yes	no
Open Channel Practices					
Grass Swale	area	yes	yes	no	no
Bioswale	volume	yes	yes	yes	no
Wet Swale	volume	yes	no	yes	no

[1] To meet the Cp_v requirements the geotechnical investigation shall indicate that the volume can be infiltrated within 48 hours
[2] If reuse is applied to vegetation to allow infiltration into natural soil
[3] Soil testing and water table elevation must support

Table 3.3 Structural Practices and Their Function

Structural Practices and Their Function				
	Water Quality Volume (WQ_v)[1]	**Recharge Volume (Re_v)**	**Channel Protection Volume (Cp_v)**	**Flood Protection (q_{p10} and q_f)**
Stormwater Ponds				
Wet Extended Detention Pond	yes	no	yes	yes
Wet Pond	yes	yes	no	yes
Multiple Pond System	yes with permanent pool	yes	yes with extended detention	yes
Dry Extended Detention Pond	no	no	yes	yes
Dry Detention pond	no	no	no	yes
Stormwater Wetlands				
Shallow Wetlands	yes	yes	no	yes
Extended Detention Shallow Wetlands	yes	yes	yes	yes
Stormwater Infiltration				
Infiltration Trench	yes	yes	yes	yes
Infiltration Basin	yes	yes	yes	yes
Stormwater Filtering Practices				
Bioretention	yes	yes if sump below underdrain	yes[2]	yes[2]
Submerged Gravel Wetland	yes	no	yes[2]	yes[2]
Surface Sand Filter	yes	yes if sump below underdrain	yes[2]	yes[2]
Perimeter Sand Filter	yes	no	yes[2]	yes[2]
Underground Sand Filter	yes	no	yes[2]	yes[2]
Rainwater Harvesting	yes	maybe[3]	yes	yes

[1] Structural practices can only be used to manage the required WQ_v for redevelopment
[2] q_p and/or q_f may be provided above or adjacent to the filter. When provided above the filter, WQ_v and/or Cp_v volume may not be used to meet q_f or q_p requirements
[3] Re_v provided when reuse is landscape irrigation

3.0.4 General Performance Criteria for Stormwater Practices

This Manual provides the requirements for proposed ESD and structural practices to meet minimum stormwater management requirements. While there are many performance criteria common to ESD practices and structural practices, most of the structural practices require the addition of a detailed geotechnical analysis, a structural engineering design, and for embankment practices, an understanding of downstream risk should the embankment fail. The location of a proposed stormwater management practice may determine additional restrictions and standards.

This Manual does not cover requirements for other state, local, or federal approvals including what is needed to obtain small pond approval or an MDE issued dam safety permit. Both the designer and the approval authority shall be familiar with all additional design, approval, and permitting criteria.

Below are some important considerations that shall be followed in addition to the design criteria described in each BMP section.

3.0.4.1 Embankments

1. Any stormwater management BMP, including ESD practices, that uses an embankment for impounding water shall be designed and constructed in accordance with the latest MDE dam safety criteria. The criteria vary depending on the category of the embankment. The embankment categories are (1) culvert; (2) exempt pond; (3) excavated pond; (4) small pond; and (5) dam. MDE also has criteria for enclosed basins (i.e., tanks) such as underground storage facilities. In addition to stormwater management approval, embankments classified as small ponds shall obtain approval from the local Soil Conservation District.

2. Underground BMPs with a total internal volume greater than 1.5 acre-feet shall be submitted to the MDE to determine whether a dam safety permit is required.

3. Stormwater BMPs with embankments that are exempt from obtaining small pond approval or a dam safety permit shall conform to the following minimum design and construction criteria:
    - For BMPs with a maximum storage volume (i.e., brim full) ≤ 8,000 ft^3:
        - The freeboard provided above the design WSEL for the 10-year 24-hour storm shall be at least 6 inches. For BMPs designed off-line from the primary conveyance, the 10-year WSEL will reflect the off-line configuration.
        - Any overflow standpipe shall be fitted with a trash rack to prevent trash and debris from entering the pipe.
        - The control structure shall be designed for anti-flotation.
        - The principal spillway pipe shall not be placed on gravel.
        - The principal spillway outfall shall be designed for safe, stable, and non-erosive discharges for the 10-year 24-hour design storm.

- The fill material for the embankment shall conform to MDE's dam safety criteria except that neither a cutoff trench nor impervious core is required.

- For BMPs with maximum storage volume (i.e., brim full) > 8,000 ft^3:
  - The freeboard provided above the design water surface elevation for the 10-year storm shall be at least 12 inches. For BMPs designed off-line from the primary conveyance, the 10-year 24-hour WSE will reflect the off-line configuration.
  - Material and construction specifications for the principal spillway shall be in accordance with the MDE's dam safety criteria. The fill material for the embankment shall conform to MDE's dam safety criteria except that neither a cutoff trench nor impervious core is required.
  - The control structure shall be designed for anti-floatation and anti-vortex and shall include a trash-rack designed in accordance with MDE's dam safety criteria.
  - The principal spillway outfall shall be designed for safe, stable, and non-erosive discharges for the 10-year 24-hour design storm. For BMPs designed off-line from the primary conveyance, the 10-year 24-hour discharge rate will reflect the off-line configuration.
  - The embankment shall be free of woody vegetation.

3.0.4.2 Liners

When a BMP is located in gravelly sands or fractured bedrock, a liner may be needed to either prevent groundwater contamination or to sustain a permanent pool. A liner shall be provided in karst topography and for hotspot runoff to maintain structural stability and prevent groundwater contamination.

Impermeable liners may be either clay or geomembrane. Clay liners shall have a minimum thickness of 12 inches. Clay soil material shall meet a particle size of a minimum 15% passing the #200 sieve and a maximum permeability of 1 x 10^{-5} cm/sec. Refer to Appendix I materiel specifications for geomembrane liners.

3.0.5 Chapter Outline

The remainder of this Chapter presents the stormwater best management practices and their associated design criteria. Section 3.1 presents the ESD practices and their design criteria, and Section 3.2 presents the structural practices and their design criteria. Within each section the BMPs are grouped by subcategories that have similar treatment processes. The design standards for each BMP are presented to include the following design topics. Where there is no specific State minimum criteria for a particular design topic for a specific BMP the design topic has been omitted.

- Function and Configuration
- Site Conditions (topography; soils and groundwater; setbacks and clearances; safety and access; hotspot runoff)

- Design Criteria (drainage area; pretreatment; conveyance; layout, dimensions, and treatment layers; underdrains, cleanouts, and observation wells)
- Sizing Criteria
- Landscape Plan
- Summary Table
- Practice Schematics

BMP selection considerations are discussed in Chapter 4. Construction inspection criteria common to all BMPs, and specific BMP construction and inspection requirements and material specifications can be found in Appendix I.

3.1 Environmental Site Design Practices

ESD practices are small-scale stormwater management practices designed to be distributed across developed areas to maintain predevelopment groundwater recharge and promote treating stormwater runoff closer to the source. In natural conditions, rainwater from smaller storms gathers in smaller areas like swales, vernal pools, and on the forest floor where it infiltrates into the ground or slowly flows into small streams. The drainage area to an ESD practice is limited to recreate this natural stormwater runoff storage, infiltration, and slow release typical of a dense wooded area. ESD practices are grouped by the following:

- Non-structural Practices
- Alternative Surfaces
- Micro-scale Practices
- Open Channel Practices

ESD practices shall be used to provide water quality treatment for new development. Non-structural practices shall be designed to treat the full required rainfall (P) for the drainage area to them. There are no partial credits available for these practices. ESD practices shall be used to provide channel protection where the Cp_v requirement from the discharge point of the development site is no larger than 8,000 ft^3. Except for non-structural practices, ESD practices shall be designed to bypass larger stormwater runoff flows to improve longevity and reduce maintenance issues.

3.1.1 Non-structural Practices

Non-structural practices (e.g., disconnection of rooftop runoff, sheetflow to conservation areas), can be used to "disconnect" impervious cover, effectively reducing the impervious area that requires water quality treatment. Disconnecting impervious area requires runoff to flow from an impervious area to a vegetated area where filtration and infiltration can occur, thereby reducing the amount of runoff that leaves the development site. The stormwater management criteria for new development and redevelopment provide a strong incentive to reduce or disconnect the development site impervious area. Storage requirements for all five Statewide Stormwater Management Criteria are directly related to impervious cover. Thus, reductions in the amount of impervious cover requiring treatment may result in smaller required storage volumes.

Non-structural practices are area-based and can only be used to provide WQ_v and Re_v management. In doing so, non-structural practices must be designed to treat the full rainfall depth (P) for the treated impervious area. There is no disconnection credit for partial treatment. These practices are also not available for managing Cp_v, q_p, or q_f. Therefore, the impervious surfaces disconnected using non-structural practices are included in the required treatment for channel protection and flood protection.

Non-structural practices combine relatively simple features, grading, and landscaping to divert runoff into vegetated areas and away from conventional storm water conveyance systems. Runoff flows over these areas, filters through the vegetation, and soaks into the ground. Runoff must be conveyed as sheetflow into and through these disconnection areas. As depth and velocity of flow increase, runoff concentrates and the ability of vegetation to filter and detain runoff diminishes rapidly. Consequently, requirements and conditions for non-structural practices reflect the need to maintain sheetflow conditions.

Non-structural practices include:

- Disconnection of Rooftop Runoff
- Disconnection of Non-Rooftop Runoff
- Sheetflow to Conservation Areas

3.1.1.1 Disconnection of Rooftop Runoff

Rooftop disconnection is an area-based ESD practice that directs flow from a roof runoff collection system (downspout or similar device) onto vegetated areas where it can soak into or filter through the ground. This disconnects the rooftop impervious area from the conventional storm water conveyance system and reduces both runoff volume and pollutants delivered to receiving waters. To function well, the rooftop disconnection credit is dependent on several site conditions including roof collection system discharge location, flow path length and slope, land cover, and soil type.

Function and Configuration:

There are many opportunities for disconnecting rooftops in both new and redevelopment designs. Stormwater runoff discharged from the rooftop collection system may be directed to undisturbed natural areas (e.g., vegetated buffers) or landscaped areas (e.g., lawns,).

When all design requirements listed below are met, the contributing rooftop area is considered disconnected and can be removed from the impervious area required to be treated for WQ_v and Re_v. Thus no additional water quality treatment or Re_v is required for these areas. When calculating the required Cp_v or analyzing for q_p and q_f, the contributing rooftop area is considered impervious.

Site Conditions:

1. **Soils and Groundwater:** Rooftop disconnections work best in undisturbed, permeable soils that allow runoff to infiltrate. The underlying soils of the disconnection flow path shall be HSG A, B, or C soils (e.g., sands, sandy loams, loams). If HSG D soils or soils that are compacted by construction equipment, these soils shall be tilled and/or amended to increase permeability. Clayey soils or soils that have been compacted by construction greatly reduce the effectiveness of this practice.

2. **Setbacks and Clearances:** The discharge from the vegetated treatment area shall be at least 10 feet from the nearest impervious surface of similar or lower elevation to prevent reconnection.

3. **Hotspot Runoff:** Disconnections should not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitation:** The drainage area to each rooftop collection system discharge shall be 500 ft^2 or less to prevent concentration of flow within the pervious, vegetated treatment area.

2. **Conveyance:**
   - Runoff from each rooftop collection system shall drain separately from other disconnects and runoff conveyances, in a safe and non-erosive manner over the entire length of the disconnection area. Discharges from rooftop collection systems shall not join each other or flow onto impervious areas prior to reaching the required disconnection flow length.
   - Runoff must be conveyed as sheetflow from the rooftop collection system, through and across the required disconnection flow length. Level spreaders may be needed at the rooftop collection system discharge to dissipate flow.

Sizing Criteria:

1. The length of the disconnection flow path shall be 75 feet or greater and must be located within the property on which the development site is located.

2. Runoff must be conveyed as sheetflow from the rooftop collection system, through and across the required disconnection flow length. Level spreaders may be needed at the rooftop collection system discharge to dissipate flow.

3. The stormwater runoff from the rooftop system shall remain in sheetflow on an average slope ≤ 5% across the entire vegetated disconnected flow length.

Landscape Plan:

1. Vegetated disconnection areas shall be identified on the construction plans and notations related to grading and construction operations shall be included.

2. Groundcover should be provided after any soil amendments are used. Turf grass is the most common groundcover in residential applications. However, trees and shrubs as well as other herbaceous plants will enhance infiltration and evapotranspiration of runoff.

Figure 3.1 Disconnection of Rooftop Runoff

(Page intentionally left blank for future detail)

3.1.1.2 Disconnection of Non-Rooftop Runoff

Non-rooftop disconnection is an area-based ESD practice where flow is directed from impervious surfaces onto vegetated areas where it can soak into or filter through the ground. This disconnects impervious surfaces from the conventional stormwater conveyance system, reducing both runoff volume and pollutants delivered to receiving waters. Non-rooftop disconnection is commonly applied to smaller or narrower impervious areas like driveways, narrower open section roads, and small parking lots. Its performance is dependent on several site conditions including permeable flow path length and slope, soils, and compaction.

Function and Configuration:

To disconnect impervious surfaces in both new and redevelopment designs, runoff shall be directed as sheetflow to and over undisturbed natural areas (e.g., vegetated buffers) or vegetated areas (e.g., lawns,). Non-rooftop disconnection is applicable in commercial, industrial, and residential settings.

Non-rooftop disconnection credit is used for providing water quality treatment and groundwater recharge. When all design requirements listed below are met, the contributing impervious area is considered disconnected and can be removed from the impervious area required to be treated for WQ_v and Re_v. Thus, no additional water quality treatment or Re_v is required for these areas. When calculating the required Cp_v or analyzing for q_p and q_f, the contributing disconnection area is considered impervious.

Site Conditions:

1. **Soils and Groundwater:** Non-rooftop disconnections work best in undisturbed, permeable soils that allow runoff to infiltrate. The underlying soils of the disconnection flow path shall be HSG A, B, or C soils (e.g., sands, sandy loams, loams). If HSG D soils or soils that are compacted by construction equipment, these soils shall be tilled and/or amended to increase permeability. Non-rooftop disconnection works best when directed over undisturbed, permeable soils that allow runoff to infiltrate. Clayey soils or soils that have been compacted by construction greatly reduce the effectiveness of this practice.

2. **Setbacks and Clearances:** The discharge from the vegetated treatment area shall be at least 10 feet from the nearest impervious surface of similar or lower elevation to prevent reconnection.

3. **Hotspot Runoff:** Disconnections should not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitation:**
   - The drainage area to each disconnection shall be 1,000 ft2 or less. The drainage area may be comprised of a combination of impervious and pervious area.
   - The impervious area to each disconnection should be small enough to prevent concentrated flow.
   - The maximum length of the contributing impervious area flow path shall be 75 feet.
   - The maximum length of the contributing pervious area flow path shall be 150 feet.

2. **Conveyance:**
   - Runoff shall be conveyed as sheetflow onto and across the disconnection flow path to maintain proper impervious disconnection.
   - Runoff from the impervious area shall be conveyed in a safe and non-erosive manner through the disconnection flow path (pervious area) to the property line or downstream BMP. A 1- to 2-foot wide gravel (typ. No. 67 stone) transition strip should be provided from the impervious area to the disconnection flow path (pervious area) to assure that runoff will flow in a safe and non-erosive manner.

Sizing Criteria:

1. The pervious vegetated area directly down gradient of the impervious cover is considered the disconnection. The length of the disconnection or disconnection flow path shall be equal to or greater than the contributing impervious flow length and must be located within the property on which the development site is located.

2. Runoff must be conveyed as sheetflow from the impervious area, through and across the required disconnection flow length. Level spreaders may be needed at the discharge to dissipate flow.

3. The disconnected flow shall be directed away from buildings to prevent water damage to basements and foundations. If slopes are too steep (> 5%), a series of terraces or berms may be required to maintain sheetflow. These terraces may be constructed of landscaping stones, timber, or earthen berms.

Landscape Plan:

1. Areas receiving disconnected runoff shall be identified on the landscaping plans with notations related to grading and construction operations.

2. Groundcover vegetation shall be provided after any soil amendments are used. Turf grass is the most common groundcover in residential applications. Trees and shrubs as well as other herbaceous plants will enhance infiltration and evapotranspiration of runoff.

Figure 3.2 Non-Rooftop Disconnection

(Page intentionally left blank for future detail)

3.1.1.3 Sheetflow to Conservation Areas

The sheetflow to conservation area credit is a non-structural ESD area-based practice where stormwater runoff from developed land flows through adjacent natural areas or buffers to soak into or filter through the ground. These conservation areas are required to have a minimum width and must be protected from disturbance via a conservation easement. This practice is dependent on several site conditions including natural or landscape buffer size, contributing flow path length, slope, and soil compaction.

Function and Configuration:

The sheetflow to conservation area credit can be used in most development applications where existing stream buffers and other natural areas are protected, expanded, or created during project planning and stormwater runoff is directed through these areas. When runoff from developed areas is directed into a conservation area meeting the criteria below, the contributing impervious area is considered disconnected and can be removed from the impervious area required to be treated. Thus, no additional water quality treatment or Re_v is required for these areas. When calculating the required Cp_v or analyzing for q_p and q_f, the contributing impervious areas within the conservation area are considered impervious.

Site Conditions:

1. **Safety and Access:** Conservation areas shall be protected by an acceptable easement or other enforceable instrument that ensures perpetual protection of the area. The easement shall clearly specify how the natural area vegetation will be managed, and boundaries will be marked. Public maintenance access and formal, legal protection are essential for long-term viability of conservation areas. Acceptable conservation easements, vegetation management plans, or other enforceable instruments are required to prevent encroachment by surrounding landowners, minimize invasive or noxious plant growth, and protect conservation areas from disturbance.

2. **Hotspot Runoff:** Conservation areas shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitation:**
   - o The maximum length of the contributing impervious area flow path shall be 75 feet.
   - o The maximum length of the contributing pervious area flow path shall be 150 feet.

2. **Layout, Dimensions, and Treatment Layers:** Conservation areas may include existing natural resources, created or restored resources, or a combination of both.

3. **Conveyance:** Runoff shall enter conservation areas as sheetflow to enhance performance and prevent erosion. The average contributing overland slope shall be 5% or less. Alternatively, a level-spreading device, a gravel diaphragm, or infiltration berm may be constructed along or parallel to a contour line to redistribute flow prior to entering designated conservation areas.

Sizing Criteria:

1. Conservation areas shall be 20,000 square feet or larger.

2. Conservation areas shall be wide enough to effectively treat runoff and protect natural resources. The minimum effective width for conservation areas shall be 50 feet.

Landscape Plan:

1. Construction plans shall clearly specify how vegetation within buffers will be established and managed. These plans should include plants that are native or adapted to Maryland and procedures for preventing noxious or invasive plants. Managed turf (e.g., playgrounds, regularly mown and maintained open areas) is not an acceptable form of vegetation management.

Figure 3.3 Sheetflow to Conservation Areas

(Page intentionally left blank for future detail)

Table 3.4 Summary of Design Elements for Rooftop and Non-rooftop Disconnection and Sheetflow to Conservation Area Credits

Design Element	
Application	Used with new development and redevelopment Area-based practices may be used to meet full water quality treatment and Re_v Partial treatment is not allowed Impervious area directed to treatment area is considered disconnected for WQ_v and Re_v requirements
Drainage Area	Rooftop Disconnection Credit: 500 ft^2 to each downspout discharge Non-rooftop Disconnection Credit: 1000 ft^2 to each vegetated treatment area
Sizing Criteria	Rooftop Disconnection Credit: The minimum length of the disconnection flow path = 15 feet Non-rooftop Disconnection Credit: Disconnection flow path length shall be ≥ the contributing impervious area flow path length The maximum contributing impervious flow path length = 75 feet The maximum contributing pervious flow path = 150 feet Sheetflow to Conservation Area Credit: The minimum effective width for conservation areas shall be 50 feet Conservation areas shall be ≥ 20,000 ft^2 The maximum contributing impervious flow path length = 75 feet The maximum contributing pervious flow path =150 feet
Slope	Maximum slope of disconnection flow path ≤ 5%
On-line/Off-line	Sheetflow may be on-line
Soil type	Rooftop and Non-rooftop Disconnection Credit: HSG A, B, or C soils Can be used with HSG D soils with tilling or soil amendments
Setbacks	Rooftop and Non-rooftop Disconnection Credit: Discharge from vegetated disconnection area to be a minimum of 10 feet from adjacent impervious surfaces

3.1.2 Alternative Surfaces

An effective method to reduce impervious surfaces on residential, commercial, and industrial development sites is to use more permeable alternatives. Rooftops, driveways, parking areas and other impervious surfaces may be replaced with more permeable alternatives. Green roofs can provide much needed green space in urban or high-density developments. Whether made from porous asphalt or concrete, interlocking pavers, or reinforced turf, permeable pavements are a cost-effective alternative for parking lot and roadway surfaces.

Alternative surface practices include:

- Permeable Pavements
- Reinforced Turf
- Green Roofs

Permeable pavements and reinforced turf are considered area-based ESD practices. A green roof is considered a volume-based ESD practice.

3.1.2.1 Permeable Pavements

Permeable pavements are area-based ESD practices that may be used in place of conventional impervious surfaces to reduce development site impervious area. While there are many different materials commercially available, permeable pavements may be divided into three basic types: porous bituminous asphalt, porous concrete, and interlocking concrete paving blocks or grid pavers. Permeable pavements typically consist of a porous surface layer over a uniformly graded stone or sand drainage system. Stormwater drains through the surface layer, is captured in the drainage system, and infiltrates into the surrounding soils. Using permeable pavements as an alternative will reduce the amount of impervious cover on the development site requiring water quality treatment and groundwater recharge and may help mitigate temperature increases.

Function and Configuration:

Permeable pavements may be used in place of impervious surfaces for parking lots, driveways, plazas, sidewalks, and access roads in both new and redevelopment applications in residential, commercial, and industrial projects. They are particularly useful in high-density areas where space is limited for other stormwater practices. Rainwater falling on the permeable pavement surface passes through and is temporarily stored in the subbase material and slowly infiltrates into the underlying soils. Permeable pavements can be used to address the WQ_v and Re_v requirement. Permeable pavements shall not be used to address the Cp_v requirement or be used to manage q_p or q_f.

When designed according to the guidance provided below, areas covered by permeable pavements will have runoff characteristics more closely resembling vegetated areas. The capacity of permeable pavements to capture and detain stormwater is governed by the storage capacity, compaction of the subbase, and in-situ soil properties. Consequently, CNs applied to these systems vary with individual design characteristics. The post development CNs shown in Table 3.6 are used when modeling runoff for q_p or q_f.

Site Conditions:

1. **Topography:** The slope of the permeable pavement shall be at least 1% but no greater than 5%. Any grade adjustments requiring fill shall be accomplished using the subbase material. Permeable pavements may be placed in sloped areas by terracing levels along existing contours.

2. **Soils and Groundwater:**
   - The presence of sandy and silty soils is critical to successful application of permeable pavements. The underlying soils shall be HSG A, B or C soils.
   - Permeable pavements shall not be installed in HSG D soils or on areas of compacted fill. Underlying soil types and condition shall be field verified prior to final design.

- Ground water levels will help determine the stone reservoir thickness used. The probability of practice failure increases if the reservoir intercepts groundwater. The invert of the subbase reservoir shall be at least four feet above (two feet on the Eastern Shore) the seasonally high ground water table.
- Soils investigation shall be conducted in accordance with Appendix A.

3. **Setbacks and Clearances:**
   - Permeable pavements should not be used in areas where there are risks for foundation damage, basement flooding, interference with subsurface sewage disposal systems, or detrimental impacts to other underground structures.
   - Permeable pavements shall be located down gradient of building structures and be setback at least 10 feet from buildings, 50 feet from confined water supply wells, 100 feet from unconfined water supply wells, and 25 feet from septic systems.
   - Permeable pavements shall also be sized and located to meet minimum local requirements for underground utility clearance.

4. **Hotspot Runoff:** Permeable pavements shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitation:**
   - Permeable pavements are an at-source practice for reducing the effects of impervious cover and addressing WQv and Rev. These practices are used to treat the rain falling directly on them. Stormwater runoff from adjacent areas (or "run-on") shall not be directed to permeable pavements.
   - Most permeable pavement alternatives have a lower load bearing capacity than conventional pavements. Therefore, applications should be limited to locations that do not receive heavy vehicle traffic and where sub soils are not compacted. Product selection shall follow manufacturers' recommendations for the intended use. Pavement systems conforming to the specifications found in Appendix I should be structurally stable for their intended typical (e.g., light duty) applications.

2. **Conveyance:**
   - Runoff shall sheetflow across permeable pavements. The slope of paved surfaces shall be gradual to prevent ponding of water on the surface and within the subbase.
   - Permeable pavements shall be designed off-line.
   - Runoff from adjacent areas shall be diverted away from the practice and to a stable conveyance system unless these areas are treated using infiltration under the permeable pavement. Refer to the Section on infiltration practices for design criteria.

- o Pavement systems shall include an alternate mode for rainfall to enter the subbase reservoir. In curbless designs, this may consist of a two-foot wide stone edge drain. Raised inlets may be required in curbed applications.

3. **Layout, Dimensions, and Treatment Layers::**
   - o A subbase layer of a clean, uniformly graded aggregate with a porosity (n) of 30% (1.5" to 2" stone is preferred) shall be used below the pavement surface.
   - o The subbase may be 6" or 9 thick in accordance with Table 3.5.
   - o Filter cloth shall not be used between the subbase and sub soils.
   - o If needed, a 12" layer of sand or pea gravel (⅛" to ⅜" stone) may be used to act as a bridging layer between the subbase reservoir and subsurface soils.

4. **Underdrains, Cleanouts, and Observation Wells:** The bottom of the subbase shall be level to enhance distribution and reduce ponding within the reservoir. A network of perforated pipes may be used to uniformly distribute runoff over the bed bottom. Perforated pipes may also be used to connect structures (e.g., cleanouts, inlets) located within the permeable pavement section. The underdrain shall not be wrapped in geotextile.

Sizing Criteria:

1. Pavement surfaces shall have a permeability of eight inches per hour or greater to convey water into the subbase rapidly.

2. The area of permeable pavement is considered disconnected when the subbase thickness meets the criteria shown in Table 3.5.

3. All permeable pavements shall be designed to ensure that water surface elevations for the 10-year 24-hour design storm do not rise into the pavement to prevent freeze/thaw damage to the surface.

4. For the purposes of modeling the drainage area and sizing downstream BMPs for WQ_v, Cp_v, q_{p10}, and q_f, the post development CN for the permeable pavement shall be determined for different HSCs using Table 3.6.

5. Designs should include overflow structures like overdrains, inlets, edge drains, or similar devices that will convey excess runoff safely to a stable outfall.

Table 3.5 Portion of Permeable Pavement Area Disconnection

Subbase Thickness	Rainfall Zone
6 inches	Western
9 inches	Central and Eastern

Table 3.6 Post Development CNs

	Hydrologic Soil Group		
	A	**B**	**C**
CN	76	85	89

Landscape Plan:

1. Permeable pavement shall be identified on landscaping plans. Trees and shrubs should not be located adjacent to asphalt and concrete where damage by root penetration and clogging from leaves are a concern.

Figure 3.4 Examples of Permeable Pavements

(Page intentionally left blank for future detail)

3.1.2.2 Reinforced Turf

Reinforced Turf is an area-based ESD practice that may be used in place of impervious surfaces to reduce development site impervious area. Reinforced turf consists of interlocking structural units with open areas for placing gravel or growing grass. These systems are suitable for light traffic loads and are commonly used for emergency vehicle access roads, maintenance access roads, and overflow or occasionally used parking.

Function and Configuration:

Reinforced turf is effective for reducing imperviousness in parking lots, driveways, plazas, and access roads in both new and redevelopment applications in residential, commercial, and industrial projects. It is particularly useful in high-density areas where space is limited for other stormwater practices. Because reinforced turf is an open load-bearing matrix within a vegetated or gravel surface, runoff characteristics are similar to open space in good condition or gravel.

Reinforced turf can be used to address the WQ_v and Re_v requirement for the area of the reinforced turf only. Reinforce turf does not address WQv and Rev for any areas draining to the reinforced turf. When designed according to the guidance provided below, areas covered by reinforce turf will have runoff characteristics more closely resembling vegetated areas. Reinforced turf shall not be used to address the Cp_v requirement or be used to manage q_p or q_f.

Site Conditions:

1. **Topography:** The slope of reinforced turf shall be at least 1% but no greater than 5%. Reinforced turf applications may be placed in steeper sloped areas by terracing levels along existing contours.

2. **Soils and Groundwater:**
   - Reinforced turf shall not be placed on areas of compacted fill.
   - Reinforced turf works best in sandy soils, and shall only be installed in HSG A. B, or C soils for maximum effectiveness.
   - Soils investigation shall be conducted in accordance with Appendix A.

3. **Setbacks and Clearances:** Reinforced turf should be sized and located to meet minimum local requirements for underground utility clearance.

4. **Hotspot Runoff:** Reinforced turf shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitation:**
   - Reinforced turf is an at source practice for reducing impervious cover. As the impervious area draining to each application increases, effectiveness weakens. Therefore, runoff from adjacent areas should be avoided.
   - Most reinforced turf has a lower load bearing capacity than conventional pavements. Therefore, applications should be limited to locations that do not receive heavy vehicle traffic and where sub soils are not compacted. Product selection shall follow manufacturers' recommendations for the intended use. Systems conforming to the specifications found in Appendix I should be structurally stable for typical (e.g., light duty) applications.

2. **Conveyance:**
   - Runoff should sheetflow onto and across reinforced turf. Contributing drainage slopes should be moderate (≤ 5%). If slopes are too steep, then level-spreading devices may be needed to redistribute flow. Turf surfaces should be gradual (≤ 4%) to prevent ponding of water within the subbase.
   - Runoff shall flow across and exit reinforced turf in a safe and non-erosive manner. Reinforced turf should be designed off-line whenever possible.

3. **Layout, Dimensions, and Treatment Layers:**
   - A subbase layer of clean, uniformly graded stone or sand with a porosity (n) of 30% (1.5" to 2" stone is preferred) shall be used below the turf surface.
   - The subbase shall be 6" to 9" thick

Sizing Criteria:

1. The area of reinforced turf is considered disconnected based on the thickness of the subbase layer as provided in Table 3.7.

2. When designed according to the guidance provided below, reinforced turf areas are considered as permeable surfaces. For the purposes of modeling the drainage area and sizing downstream BMPs for WQ_v, Cp_v, q_{p10}, and q_f, post development CN for the reinforced turf shall be determined for different HSG soils using Table 3.8. Post development CNs for reinforced turf applications shall follow those in Table 3.8 depending on the media placed in the open areas.

Table 3.7 Portion of Reinforced Turf Area Disconnection

Subbase Thickness	Rainfall Zone
6 inches	Western
9 inches	Central and Eastern

Table 3.8 Post Development CN for Reinforced Turf

Media	Hydrologic Soil Group		
	A	B	C
grass	49	69	79
gravel	76	85	89

Landscape Plan:

1. Reinforced turf shall be identified on construction plans. Woody vegetation should not be located adjacent to reinforced turf where damage by root penetration is a concern.

Table 3.9 Summary of Design Elements for Reinforced Turf

Design Element	
Application	Used with new development and redevelopment, Used to treat full runoff for WQ_v and Re_v Shall not be used to manage Cp_v, qp, or qf
Drainage Area	Treat rain falling directly on the surface Runoff from adjacent areas to be directed away from alternative surfaces
On-line/Off-line	Off-line designs are preferrable Provide alternative means for rainfall to enter subbase
Soil type	HSG A, B, C Shall not be installed on HSG D or compacted fill
Groundwater	At least 4 ft below bottom of gravel layer (2 ft for Eastern Shore)
Design Runoff Volume	minimum subbase thickness: 6 inches in Western Rainfall Zone; 9 inches in Central/Eastern Rainfall Zone
Filter Media	A subbase layer of a clean, uniformly graded aggregate with a porosity (n) of 30% (1.5” to 2” stone is preferred) below the interlocking structure surface
Underdrain	A network of perforated pipes may be used to distribute runoff or to connect structures (e.g., cleanouts, inlets) located within the permeable pavement section
Vegetation	Grass or gravel as fill for the open areas of interlocking units

3.1.2.3 Green Roofs

Green roofs are alternative surfaces that replace conventional construction materials and include a protective covering of filtering media and vegetation. Also known as vegetated roofs, roof gardens, or eco-roofs, green roofs may be used in place of traditional flat or pitched roofs to reduce the stormwater impacts of impervious cover. Green roofs may produce less heat than conventional roof systems, thereby reducing the temperature of stormwater runoff which is especially important for thermally sensitive watersheds.

There are two basic green roof designs that are distinguished by growing medium thickness and the plant varieties that are used. The more common or "extensive" green roof is a lightweight system where the thickness of the growing medium layer is two to six inches. This limits applicable plants to low-growing, hardy herbaceous varieties. "Intensive" green roofs have thicker growing medium (eight inches or greater) and are capable of supporting more diverse plant communities including trees and shrubs. A more robust structural loading capacity is needed to support the additional weight of the growing medium and plants. Intensive green roofs are more complex and expensive to design, construct, and maintain, and are therefore, less commonly used.

Function and Configuration:

Green roofs are considered a volume-based ESD practice that can be used to manage the WQ_v and Cp_v. Because impermeable liners are an integral component in all systems, green roofs do not provide groundwater recharge. Therefore, additional treatment is needed to compensate for the loss of recharge from these rooftop areas. The Re_v for the rooftop area may be provided in separate ESD infiltration practices.

Site Conditions:

1. **Topography:** Green roofs are not suitable for use on roofs with slopes steeper than 30% (i.e., 4:12). Green roofs with pitches steeper than 2:12 shall include supplemental measures (e.g., slope bars, rigid stabilization panels, reinforcing mesh) to enhance stability and prevent media sliding.

2. **Setbacks and Clearances:** The location of existing and proposed utilities (e.g., HVAC, gutters, downspouts, electricity) will influence the design and construction of green roofs.

Design Criteria:

1. **Drainage Area and Size Limitation:**
   - Runoff from adjacent roofs should not drain to the green roof. If bypassing a green roof is impractical, an overflow device (e.g., gutter, deck drain) should be used.

2. **Conveyance:**
   - Runoff shall flow through and exit green roof systems in a safe and non-erosive manner.
   - Building drainage (e.g., gutters, deck drains, scuppers) must be capable of managing large rainfall events without inundating the roof. Overflow structures shall be capable of passing storms larger than 1 year 24-hour design storm without inundating the roof.
   - A semi-rigid, plastic geocomposite drain or mat layer should be included to convey runoff to the building drainage system.
   - Flat roof applications may require a perforated internal network to facilitate drainage of rainfall.
   - Additionally, roof flashing should extend six inches above the media surface and be protected by counter-flashing.

3. **Layout, Dimensions, and Treatment Layers:**
   - All green roofs shall include a waterproofing system or membrane. Materials used should be durable under vegetated cover conditions and resistant to biological and root attack. A supplemental barrier may be needed to protect the waterproofing from plant roots. Materials should be durable under the conditions associated with vegetated covers.
   - Growing medium shall be non-soil engineered mixes conforming to the specifications found in Appendix I. Growing medium should generally be between two to six inches thick. Dual growing medium systems may be applied where green roof assemblies are four inches or thicker.
   - Individual layers (e.g., root barriers, drainage mats, separation geotextiles) shall conform to the specifications found in Appendix I.
   - The roof structure shall be capable of bearing the maximum predicted dead and live loads associated with green roof systems. A typical dead load ranges from 8 to 36 lbs/ft2. Live load is a function of rainfall retention (e.g., 1 inch of rain or 10 inches of snow equals 5.2 lbs/ft2). Standardized media weights and procedures (e.g., ASTM E-2397-05, E-2399-05) shall be used to establish the dead load bearing capacity of the roof. For redevelopment projects and existing buildings, additional measures (e.g., trusses, joists, columns) may be needed for support.

Sizing Criteria:

1. The WQ_v provided by a green roof system shall be determined by the direct runoff depth (Q) retained per manufacturer's specifications. The direct runoff depth retained is determined by the thickness of the roof and porosity of the media per manufacturers specifications.

2. For the purposes of calculating the required the WQ_v and Cp_v for a discharge point with a green roof, the post development CN for the green roof shall be 98. When providing Cp_v in a green roof, the direct runoff depth retained (Q) will determine the amount of Cp_v provided. When modeling for the purposes of determining q_p and q_f requirements, the post development CN for the green roof shall be 98.

Landscape Plan:

1. Vegetation is critical to the function and appearance of any green roof. A vigorous, drought-tolerant vegetative cover should be established using varieties of sedum, delosperma, or similar varieties native or suitable for growth in Maryland.

Figure 3.5 Typical Green Roof

(Page intentionally left blank for future detail)

3.1.3 Micro-Scale Practices

Micro-scale practices are small volume-based devices distributed across a development site to capture and treat stormwater runoff from small, discrete drainage areas. These practices use soil and/or stone media, and vegetation combined to provide water quality treatment, groundwater recharge, and channel protection through infiltration, filtration, evapotranspiration, rainwater harvesting, or a combination of these techniques. These practices include planted surface depressions created either through excavation or with a small berm, and a variety of rainwater collection systems. Many of these practices become structural practices when scaled up in size to treat a larger drainage area (e.g., bioretention, infiltration, and submerged gravel wetlands) as described in Section 3.2 Structural Practices.

Micro-scale practices include:

- Rain Gardens
- Infiltration Berms
- Rain Barrels
- Micro-bioretention
- Landscape Infiltration
- Dry Wells
- Pocket Submerged Gravel Wetlands

3.1.3.1 Rain Gardens

A rain garden is a shallow, excavated landscape feature or depression that temporarily holds stormwater runoff. Rain gardens are volume-based practices that typically consist of a planted soil bed of specified media, a mulch layer, and plants such as shrubs, grasses, and flowers. Captured runoff from roof drains, driveways, parking areas, and other surfaces is temporarily stored to allow slow filtration into the soil.

Function and Configuration:

Rain gardens are typically used to treat runoff from small impervious areas like rooftops, driveways, and sidewalks. Rain gardens can be used in new and redevelopment applications. When designed with a level spreading overflow and outfall protection, they can be used where slopes require energy dissipation.

A rain garden can be used to meet WQ_v, Re_v, and Cp_v requirements when designed according to the guidance provided below. The required storage volume is provided as temporary storage above the surface of the bioretention soil media. The maximum runoff volume (i.e., WQ_v and Cp_v) that may be managed by this ESD practice is 500 ft^3. Larger water quality volumes can be managed in multiple rain gardens or other ESD practices. Larger channel protection volumes must be managed in one or more structural practices such as extended detention.

Site Conditions:

1. **Topography:** Rain gardens require relatively flat slopes (< 5%) to accommodate stormwater runoff filtering through the system. The use of infiltration berms, terracing, and timber or block retaining walls can be used on moderate slopes to break up the slope creating flatter surfaces.

2. **Soils and Groundwater:**
   - Rain gardens work best where HSG A and B soils are prevalent but can be used in areas of HSG C and D soils for providing WQ_v, Re_v, and Cp_v. Rain gardens situated in HSG C or D soils shall include the incorporation of soil compost amendments to achieve greater runoff reduction.
   - A rain garden shall not be used for areas where the rain garden will intercept seasonally high groundwater. The minimum distance between the bottom of the bioretention soil media and the seasonally high groundwater table shall be at least two feet (1 foot on the Eastern Shore). For higher groundwater elevations, consider an infiltration berm as an alternative.

3. **Setbacks and Clearances:**

- The location of existing and proposed buildings and underground utilities (e.g., water supply wells, sewer, storm drains, electricity) will influence rain garden design and construction.
- Designers should also consider overhead electrical and telecommunication lines when selecting trees to be planted.
- The use of rain gardens on residential lots requires homeowner education to provide maintenance and prevent removal.
- Rain garden excavation in areas with heavy tree cover may damage adjacent tree root systems.

4. **Safety and Access:** The temporary surface storage may be as deep as 6 inches. In residential applications this may generate the need for safety features.

5. **Hotspot Runoff:** Rain gardens shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitation:** While there is no drainage area limit, the maximum volume that can be treated in a rain garden is 500 ft^3. Micro-bioretention or landscape infiltration should be considered when this requirement is exceeded.

2. **Conveyance:**
   - Runoff shall enter, flow through, and exit rain gardens in a safe and non-erosive manner. Energy dissipation shall be provided for downspout discharges using a plunge area, rocks, splash blocks, stone dams, etc.
   - A shallow berm surrounding the rain garden is recommended to ensure proper treatment..
   - For sloped applications, a series of rain gardens can be used as “scalloped” terraces to convey water in a non-erosive manner.

3. **Layout, Dimensions, and Treatment Layers:**
   - An appropriately sized surface storage area shall be provided with a minimum depth of 3 inches and a maximum depth of 6 inches.
   - A six to twelve-inch layer of bioretention soil medium shall be provided along the bottom of the rain garden.
   - A mulch layer two to three inches deep shall be applied above the bioretention soil media to maintain soil moisture and to prevent premature clogging.
   - The bioretention soil media and mulch shall conform to the specifications found in Appendix I.

Sizing Criteria:

1. At least 100% of the design runoff treatment volume (i.e., WQ_v or Cp_v) shall be provided as temporary ponding storage above the surface of the rain garden. The top of the bioretention soil media is considered the surface.

2. The minimum allowable surface ponding depth is 3 inches. The maximum allowable surface ponding depth is 6 inches. The ponding depth is measured from the top of the bioretention soil medium. Where stone or gravel instead of mulch is provided on the surface, the ponding depth shall be measured from the top of the stone.

3. Earthen side slopes of the ponding area shall be 3:1 (H:V) or flatter and should be vegetated with dense ground cover (either turf grass or other year-round vegetation).

Landscape Plan:

1. Landscaping requires a certain number of plants. Landscaping plans shall clearly specify how vegetation will be established and managed. Refer to Appendix H for planting requirements.

2. Plants selected for use in a rain garden should tolerate both saturated and dry conditions and be native or adapted to Maryland. Neatly trimmed shrubs, a crisp lawn edge, stone retaining walls, and other devices can be used to keep a rain garden neat and visually appealing.

Table 3.10 Summary of Design Elements for Rain Gardens

Design Element	
Application	Used with new development and redevelopment Used to treat runoff for full or partial WQ_v, Re_v, and Cp_v
Size Limitations	Use of rain gardens is limited to design runoff volumes (i.e., WQ_v or Cp_v) $\leq 500\ ft^3$
On-line/Off-line	On-line allowed
Pre-treatment	None
In the Soil Type	HSG A, B, C, and D soils Use in HSG C and D soils requires soil compost amendments
Groundwater	At least 2 ft below bottom of bioretention soil media (1 ft for Eastern Shore)
Soils Investigation	See Appendix A
Surface Storage Volume	100% of the design runoff treatment volume (i.e., WQ_v or Cp_v) provided as surface storage
Surface Side Slopes	No steeper than 3:1 (H:V) Turf grass cover preferred on side slopes
Ponding Depth	Minimum 3 inches Maximum 6 inches
Freeboard	Minimum 3 inches above design surface storage elevation (i.e., WQ_v or Cp_v)
Planting Bed	6 to 12 inches of bioretention soil media
Surface Cover	Minimum 3 inches of mulch Shredded hardwood mulch preferred
Vegetation	Follow landscaping guidance in Appendix H

Figure 3.6 Rain Garden

(Page intentionally left blank for future detail)

3.1.3.2 Infiltration Berms

An infiltration berm is a volume-based practice that temporarily stores runoff behind a small berm composed of soil that is placed along the contour of a relatively gentle slope. The berm creates a barrier to retain flow, allow filtration and infiltration, and dissipate velocities by providing sheetflow. The storage behind the berm may be constructed by excavating upslope material to create a depression or by placing a berm on top of existing grade. Sheetflow shall be maintained both into and out of the practice.

Function and Configuration:

The purpose of an infiltration berm is to augment natural stormwater conveyance by promoting sheetflow and dissipating runoff velocities. Infiltration berms may be used on gently sloping areas in residential or commercial land uses in open space or wooded areas. They shall be installed along the contour to perform effectively. Stormwater runoff from impervious areas flows to a depressed area immediately above the berm where velocities are reduced, stormwater flows through the berm, and sheetflows downslope. Infiltration berms are suitable for use in areas with a high groundwater table. This practice can be used to provide WQ_v, Re_v, and Cp_v management. To meet the Cp_v requirements the geotechnical investigation shall indicate that the volume can be infiltrated through the subsurface soil within 48 hours. The maximum runoff volume (i.e., WQ_v and Cp_v) that may be managed by this ESD practice is 2,000 ft^3. Larger WQ_v can be managed in multiple infiltration berms or other ESD practices. Larger Cp_v must be managed in one or more structural practices such as extended detention.

Site Conditions:

1. **Topography:**
   - Infiltration berms should not be installed on slopes greater than 10% to prevent erosion at the upstream toe of the berm.
   - Infiltration berms should not be installed on slopes where soils have low shear strength (or identified as "slough prone" or "landslide prone").

2. **Soils and Groundwater:**
   - Infiltration berms work best where HSG A and B soils are prevalent but can be used in areas of HSG C and D soils for meeting water quality treatment.
   - To be suitable for meeting Cp_v requirements, underlying soils shall have an infiltration rate (f) of 0.52 inches per hour or greater, as initially determined from USDA Soils Textural Triangle (See Appendix G) classification and subsequently confirmed by geotechnical field tests. Approved geotechnical testing procedures for feasibility and design are outlined in Appendix A.
   - Subsurface soils shall be uncompacted and may need to be scarified to encourage infiltration.

3. **Setbacks and Clearances:** Berms may be threaded carefully along the contour of wooded slopes to avoid disturbing existing vegetation.

4. **Hotspot Runoff:** Infiltration berms shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitations:** The drainage area should be small enough to prevent flow concentration upslope of the berm. The maximum volume that can be treated in an infiltration berm is 2,000 ft^3. Maximum length of impervious area draining to an infiltration berm shall be 75 feet, and the maximum length of pervious area shall be 150 feet.

2. **Conveyance:** Stormwater discharges greater than one-year, 24-hour design storm shall flow over the berm at non-erosive velocities.

3. **Layout, Dimensions, and Treatment Layers:**
   - A berm shall consist of a six-inch layer of uncompacted topsoil with an interior of bioretention soil media.
   - The height of the berm cannot be greater than 3 feet measured from the toe of the upstream slope.
   - Berms shall be installed along the contour at a constant elevation and be level for the length of the berm.
   - When used in a series along a slope, the elevation at the downstream toe of each berm shall be the same elevation as the crest (i.e., berm elevation) of the next berm downslope.
   - The crest of the berm shall be a minimum of two feet wide.
   - The berm shall be graded so that a concave shape is provided at the up-gradient toe. Tie the berm into existing grading at the elevation that corresponds to the required storage volume.
   - Side slopes shall be 3:1 (H:V) or flatter.

Sizing Criteria:

1. The storage volume created behind and up to the crest of the berm may be used to address WQ_v, Re_v and Cp_v.

2. Berm length shall be a minimum of 13 feet for every 1cfs of flow.

Landscape Plan:

1. Areas upslope of the berm should be planted with native meadow vegetation and shrubs. Turf grass shall be used on berms.

Table 3.11 Summary of Design Elements for Infiltration Berms

Design Element	
Application	Used with new development and redevelopment Used to treat runoff for full or partial WQ_v and Re_v May be used to treat full or partial runoff for Cp_v when subsoils have infiltration rate ≥ 0.52 in/hr
Size Limitations	Use limited to impervious contributing flow length ≤ 75 ft Use limited to pervious contributing flow length ≤ 150 ft Use limited to design runoff volumes ≤ 2,000 cf for WQ_v and/or Cp_v
On-line/Off-line	For infiltration berms, stormwater discharges greater than the one-year, 24-hour design storm shall flow over the berm at non-erosive velocities
Pre-treatment	Runoff shall enter the infiltration berm at the surface through a gravel bed (pea gravel diaphragm)
Soil type	Applicable for HSG A and B soils Can be used in HSG C and D soils if soil compost amendments are provided Cp_v management requires soils with infiltration rate of 0.52 in/hr
Groundwater	No requirement
Soils Investigation	Required if managing Cp_v See Appendix A
Storage Volume	100% of the design runoff treatment volume (i.e., WQ_v or Cp_v) provided as storage behind berm
Berm Dimensions	Side slopes no steeper than 3:1 (H:V) Minimum top width of 2 ft Maximum height of 3 ft (from upstream slope to top of berm) Berm length shall be a minimum of 13 feet for every 1cfs of flow
Ponding Depth	No criteria apart from maximum berm height of 3 ft
Filter Media	Berm constructed of bioretention soil media covered with topsoil and turf grass
Vegetation	Turf grass cover required on berm Native meadow vegetation and shrubs preferred upgradient of berm Follow landscaping guidance in Appendix H

Figure 3.7 Infiltration Berm

(Page intentionally left blank for future detail)

3.1.3.3 Rain Barrels

Rain barrels are volume-based practices that intercept and store rainfall from rooftop impervious surfaces for future use. Stored water may be used for non-potable water supply such as landscape irrigation. The capture and reuse of rainwater promotes conservation, as well as reduces runoff volumes and the discharge of pollutants downstream.

Function and Configuration:

Rain barrels are used for small-scale residential applications to meet the WQ_v and Re_v requirements. The pollutant removal capability of a rain barrel is directly proportional to the amount of runoff captured, stored, and reused. Therefore, the amount of runoff treated from the contributing drainage area is based on the volume captured and reused prior to the next rainfall.

Site Conditions:

1. **Setbacks and Clearances:** The proximity to building foundations should be considered for dewatering and overflow conditions.

2. **Safety and Access: Safety and Access:**
   - Access shall be provided for cleaning, inspection, and maintenance for all rain barrels. A drain plug shall also be provided to allow the system to be completely emptied if needed.
   - Rainwater storage designs need to consider the potential for freezing. During the non-growing season rain barrels may need to be dewatered.

3. **Hotspot Runoff:** Rain barrels shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitation:** The drainage area to each rooftop collection system discharge shall be 500 ft^2 or less. The drainage area to each rain barrel shall consider the rain barrel size and required rainfall depth to be treated.

2. **Pretreatment:** Screens or covers should be provided to prevent mosquitoes and other insects from entering the rain barrel.

3. **Conveyance:**
   - A stable discharge shall be provided for any dewatering.
   - Conveyance to rain barrels consists of gutters, downspouts, and pipes.

- An overflow shall be provided to pass larger storm events. The overflow should be near the top of the rain barrel and may consist of hosing or piping to direct runoff safely to a stable outfall.

Sizing Criteria:

1. Rain barrels shall be designed to capture the required rainfall depth for water quality treatment from the contributing rooftop area. For the Western rainfall region this rainfall depth is 1.0 inches. For the Central/Eastern rainfall region, this rainfall depth is 1.5 inches.

2. Common sizes for residential rain barrels range from 50 to 100 gallons. Rain barrels can be connected to increase capacity.

3. Rain barrels should provide a minimum of six inches of dead storage at the bottom.

Figure 3.8 Rain Barrels

(Page intentionally left blank for future detail)

3.1.3.4 Micro-Bioretention

Micro-bioretention practices are shallow volume-based structures that retain and treat stormwater runoff through settling, filtration, and biological and chemical transformation. Stormwater runoff is temporarily stored on the surface of the practice, filtered through a mulch layer and an underlying bioretention soil media layer composed of a mixture of sand, soil, and organic matter. Stormwater runoff then flows through a sand and pea gravel bridging layer followed by a second gravel layer that holds an underdrain. Filtered stormwater discharges through the underdrain. When additional storage is provided in excess gravel below the underdrain, micro-bioretention also provides groundwater recharge.

The treatment process used in micro-bioretention forms the basis of several BMPs in this Manual. Variants include rain gardens, landscape infiltration, bioswales, and the larger structural bioretention practices. Bioswales essentially function as linear micro-bioretention systems. All of these practices except bioretention are considered ESD practices due to their limited treatment volume.

Function and Configuration:

Micro-bioretention practices can be incorporated into parking lot islands, roadway medians, terraced slopes, residential lots, open spaces, and cul-de-sac islands. Micro-bioretention can be used to provide WQ_v, Re_v, and Cp_v. The maximum runoff volume (i.e., WQ_v and Cp_v) that may be managed by this ESD practice is 8,000 ft^3. Larger water quality volumes can be managed in multiple micro-bioretention practices or other ESD practices. Larger channel protection volumes must be managed in one or more structural practices such as extended detention.

Site Conditions:

1. **Topography:** Steep terrain affects the successful performance of micro-bioretention. These practices should be constructed on level ground. Level-spreading devices such as check dams, terraces, or berms may be needed to maintain sheet flow.

2. **Soils and Groundwater:**
   - Micro-bioretention shall be limited to HSG C and D soils. For locations with HSG A and B soils, groundwater recharge should be promoted, and an underdrain is not recommended and micro-scale landscape infiltration practices shall be used instead of micro-bioretention. Only when infiltration rates are unacceptable for micro-scale landscape infiltration or the location requires an underdrain, shall a micro-bioretention practice be used in HSG A and B soils.
   - The bottom of the micro-bioretention gravel layer shall be located at least 2 feet above the seasonally high-water table (1 foot on the Eastern Shore). Soils investigations shall include at least one test pit or boring per 1 acre of site disturbance and shall be conducted in accordance with Appendix A.

3. **Setbacks and Clearances:**
    - Micro-bioretention practices should be located down gradient from building structures and setback at least 10 feet. Micro-bioretention practices that must be located adjacent to structures should include an impermeable liner.
    - Micro-bioretention practices shall be located at least 30 feet from water supply wells and 25 feet from septic systems. If designed to provide recharge, the micro-bioretention practice shall be located at least 50 feet from confined water supply wells and 100 feet from unconfined water supply wells.
    - Micro-bioretention practices shall be sized and located to meet minimum local requirements for clearance from underground utilities.

4. **Hotspot Runoff:** When micro-bioretention practices are used to treat runoff from hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are typically found in stormwater runoff, recharge storage shall not be provided below the underdrain, and a liner shall be used to avoid contamination of groundwater. Use of an organic media filter is required to target the specific hotspot pollutants.

Design Criteria:

1. **Drainage Area and Size Limitation:** While there is no specified drainage area limit, the use of micro-bioretention is limited to treating runoff volumes of 8,000 ft^3 for both WQ_v and Cp_v.

2. **Pretreatment:** Where a runoff volume greater than 2,000 ft^3 enters a micro-bioretention as concentrated flow from a pipe or channel, a pretreatment forebay shall be provided. Refer to the sizing criteria section below.

3. **Conveyance:**
    - Runoff shall enter, flow through, and exit micro-bioretention practices in a safe and non-erosive manner.
    - Inflow may be conveyed via sheet flow or concentrated flow via depressed curbs with wheel stops, curb cuts, downspouts, storm drains, and catch basins. Concentrated points of inflow shall be protected with energy dissipation.
    - When the design volume is greater than 2000 ft^3 and is conveyed as concentrated flow into a micro-bioretention practice, the practice shall be designed off-line from the primary conveyance system. A flow splitter or other mechanism can be used to divert storms larger than the design storm around the practice to a stable, downstream conveyance system. At a minimum, volumes larger than the design storm shall be prevented from entering the micro-bioretention filter.
    - Filtered runoff shall be collected in an underdrain system and discharged safely to a stable outfall designed for non-erosive velocities for the design storm.
    - To avert short circuiting of inflow directly into the gravel media, inflow points, observation wells, etc protected with stone shall be designed to avoid cross connections with the underdrain gravel layer.

4. **Layout, Dimensions, and Treatment Layers:**
    - The filter is comprised of: the mulch layer, the bioretention soil media, the bridging layers, and the underdrain gravel layer.
    - A 3- to 12-inch-deep surface ponding area shall be provided.
    - A surface mulch layer (2 to 3 inches thick) of shredded hardwood shall be provided to enhance plant survival and inhibit weed growth. Triple-shredded hardwood mulch exhibits the lowest propensity for floating and has a high carbon to nitrogen ratio which mitigates the potential of leaching nitrogen. In special situations, coir or jute matting, river stone, or pea gravel may be acceptable alternative. When stone is provided on the surface, the ponding depth shall be measured from the top of the stone.
    - A bioretention soil media layer at least 24 inches deep and no deeper than 48 inches shall be provided.
    - A bridging layer of a minimum of 3 inches of sand and a minimum of 3 inches of pea gravel shall be placed between the bioretention soil media and the underdrain gravel layer.
    - An underdrain gravel layer at least 12 inches deep shall be provided and shall include a minimum of 3 inches of gravel above the underdrain pipe and a minimum of 3 inches below the pipe.
    - Geotextile shall not be provided along the top, bottom, or between any horizontal layer. The use of geotextile along the sides of filter is optional.

5. **Underdrains, Cleanouts, and Observation Wells:**
    - The underdrain shall be sized so that the surface storage and media filter storage fully drain within 48 hours. The diameter of underdrain shall be at least 4 inches.
    - Multiple underdrains may be necessary for micro-bioretention practices with surfaces wider than 40 feet. Each underdrain should be located no more than 20 feet from the next pipe or the edge of the filter area.
    - The preferred slope of the underdrain is 0.5%.
    - A cleanout pipe shall be located at the upgrade end of each underdrain run and also at every bend (i.e., T's and Y's). The length of pipe between cleanouts shall be no greater than 150 ft.
    - A minimum of one observation well shall be provided for every 2,000 ft2 of filter surface.
    - The observation well and cleanout can be combined. No perforations or gravel jacket shall be provided within 12 inches of the surface.
    - The top of the cleanout/observation shall extend at least 6 inches above ground and shall be protected by a cage or constructed of material resistant to breakage from lawn mowers.
    - The underdrain shall not be wrapped in geotextile.
    - Underdrains, cleanouts, and observation wells shall conform to the piping specifications found in Appendix I.

Sizing Criteria:

1. At least 75% of the design runoff treatment volume (i.e., Cp_v or WQ_v) shall be provided as temporary ponding storage above the surface of the micro-bioretention practice.

2. Where a runoff volume greater than 2,000 ft^3 enters a micro-bioretention practice as concentrated flow from a pipe or channel, a forebay shall be provided as pretreatment. The forebay may also provide a means for bypassing flows larger than the design volume away from the filter. The forebay shall be sized to hold at least 10% of the design runoff treatment volume (i.e., WQ_v or Cp_v). The forebay storage volume reduces the required above surface storage volume from 75% to 65%. Forebay volumes in excess of 10% shall not be considered as contributing to the provided storage volume.

3. The minimum allowable temporary surface ponding depth is 3 inches. The maximum allowable temporary surface ponding depth for both WQ_v and Cp_v is 12 inches. The ponding depth is measured from the top of the bioretention soil media. Where stone or gravel instead of mulch is provided on the surface, the ponding depth shall be measured from the top of the stone. In residential applications the temporary surface storage depth may generate the need for safety features.

4. At least 6 inches of freeboard shall be provided above the surface storage elevation for the design storm (WQ_v or Cp_v).

5. Earthen side slopes of the surface ponding area shall no steeper than 2:1 (H:V) in cut and 3:1 (H:V) in fill and shall have a dense vegetative cover.

6. The filter surface area of the micro-bioretention practice (A_f) should occupy the entire bottom of the surface storage, except the side slopes and limited clearances. Where there is a justified reason for this not being possible, Equation 3.1 in the Section 3.1.4 shall be used to calculate the required filter bed area.

7. The Re_v requirement may be met by providing a gravel reservoir below the invert of the underdrain to allow stored runoff to exfiltrate into the underlying soils without impeding drainage from the upper layers. The recharge reservoir should extend under the entire bottom of the filter area.

8. Micro-bioretention practices with impermeable liners or practices that are formed of concrete, brick, or other hard surfaces do not provide groundwater recharge.

9. The provided groundwater recharge volume is equal to the volume below the underdrain outflow invert, multiplied by a porosity of 0.4. The credited recharge volume cannot be larger than the runoff to the BMP for the water quality storm (i.e., WQ_v to the BMP). The provided Re_v does not count towards provided WQ_v or Cp_v.

Landscape Plan:

1. Landscaping plans shall be provided according to the guidance in Appendix H. Native and naturalized plants are preferred because they are hardier and usually require minimal nutrient or pesticide application. Aesthetically pleasing landscape designs generally enhance property value and community acceptance.

Table 3.12 Summary of Design Elements for Micro-Bioretention Facilities

Design Element	
Application	Used with new development and redevelopment Used to treat runoff for full or partial WQ_v, Re_v, and Cp_v
Size Limitations	Use of micro-bioretention is limited to runoff treatment volumes of ≤ 8,000 ft^3 for both WQ_v and Cp_v
On-line/Off-line	On-line allowed if concentrated runoff volume conveyed to practice ≤ 2,000 ft^3 On-line allowed if inflow is sheet flow Otherwise, practice must be off-line
Pre-treatment	Forebay required where concentrated inflow > 2,000 ft^3 for design runoff treatment volume Pretreatment forebay ≥ 10% of design runoff treatment volume
Soil Type	HSG C/D soils Can be used with HSG A/B when infiltration rates are unacceptable for landscape infiltration or location requires an underdrain
Groundwater	At least 2 ft below bottom of gravel layer (1 ft for Eastern Shore)
Soils Investigation	One test pit or boring per 1 acre of site disturbance indicating groundwater elevation
Surface Storage Volume	75% of the design runoff treatment volume (i.e., WQ_v or Cp_v) 65% when a forebay is used to provide 10%
Surface Side Slopes	Maximum 3:1 (H:V) for fill, no steeper than 2:1 (H:V) in cut. Dense vegetative cover on slopes
Surface Ponding Depth	Minimum 3 inches Maximum 12 inches for WQ_v and Cp_v
Freeboard	Minimum 6 inches above design surface storage elevation (i.e., 75%WQ_v or 75%Cp_v)
Filter Area	Filter must cover entire bottom of surface storage area
Recharge Storage	Gravel reservoir below underdrain outflow invert must be ≥ required Re_v Porosity of gravel media = 0.4
Filter Media	Minimum 24 inches of bioretention soil media Bridging layer of minimum 3 inches of sand and minimum 3 inches of pea gravel Minimum 10 inches of gravel (minimum 3 inches above and below underdrain)

Design Element	
Underdrain	Minimum 4-inch diameter perforated or slotted pipe Maximum 20 ft spacing from pipe to pipe Preferred slope 0.5%
Low Flow Orifice	Not to be used with micro-bioretention
Observation Wells	Minimum one per 2,000 ft^2 of filter area
Cleanouts	Provide at end of underdrain runs and at T's and Y's Maximum 150 ft pipe length between cleanouts
Surface Cover	Minimum 3 inches of mulch Shredded hardwood mulch preferred In special situations, coir or jute matting, river stone, or pea gravel may be acceptable alternative
Vegetation	Follow landscaping guidance in Appendix H

Figure 3.9 Micro-Bioretention

(Page intentionally left blank for future detail)

3.1.3.5 Landscape Infiltration

Landscape infiltration is a volume based ESD practice that, like micro-bioretention, provides storage and treatment of stormwater runoff. The difference between landscape infiltration and micro-bioretention is the absence of an underdrain. Stormwater runoff is initially stored, then filters through the mulch and filtering media and sand and gravel media below and finally infiltrates into in-situ soils. These practices can be integrated within the overall site design as landscape features in the form of constructed planters made of stone, brick, concrete, or in natural areas excavated and backfilled with stone and topsoil.

Function and Configuration:

Landscape infiltration is best implemented in residential and commercial land uses. Residential areas with compact housing such as clustered homes and townhouses can utilize small green spaces for landscape infiltration. Landscape infiltration can be used to manage the WQ_v, Re_v, and Cp_v. The amount of management provided is dependent on the surface storage and the size of the drainage area. The maximum runoff volume (i.e., WQ_v and Cp_v) that may be managed by this practice is 8,000 ft^3, which equates to 6,000 ft^3 of surface storage. Re_v is provided through infiltration and is limited by the required Re_v for the drainage area. Larger water quality volumes can be managed in multiple landscape infiltration practices or other ESD practices. Larger channel protection volumes must be managed in one or more structural practices such as extended detention.

Site Conditions:

1. **Topography**: Steep terrain affects the successful performance of landscape infiltration. These practices should be constructed on level ground or in association with level-spreading devices such as check dams, terraces, or berms that may be needed to maintain sheet flow.

2. **Soils and Groundwater:**
    - Permeable soils are critical to the successful application of landscape infiltration. Landscape infiltration shall be installed in HSG A or B soils. The depth from the bottom of the facility to the seasonal high groundwater table, bedrock, hard pan, or other confining layer shall be greater than or equal to four feet (two feet on the Eastern Shore).
    - To be suitable for meeting Cpv requirements, underlying soils shall have an infiltration rate (f) of 0.52 inches per hour or greater, as initially determined from USDA Soil Textural Triangle (See Appendix G) and subsequently confirmed by field geotechnical tests. Approved geotechnical testing procedures for feasibility and design are outlined in Appendix A. The minimum geotechnical testing is one test hole per 5,000 sf of surface area, with a minimum of two borings per facility (taken within the proposed limits of the facility).
    - Soils investigation shall be conducted in accordance with Appendix A.

3. **Setbacks and Clearances:**

- o Landscape infiltration should not be used in areas where operation may create a risk for basement flooding, interfere with subsurface sewage disposal systems, or other underground structures.
- o Landscape infiltration shall be located down gradient of building structures and shall be setback at least 10 feet from buildings, 50 feet from confined water supply wells, 100 feet from unconfined water supply wells, and 25 feet from septic systems.
- o Landscape infiltration shall be sized and located to meet minimum local requirements for clearance from underground utilities.

4. **Hotspot Runoff:**
   - o Landscape infiltration shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitations:** While there is no specified drainage area limit, the use of landscape infiltration is limited to runoff treatment volumes of 8,000 ft^3 or less for both WQ_v and Cp_v.

2. **Pretreatment:**
   - o When inflow is concentrated for storage volumes > 2,000 ft^3, a pre-treatment forebay is required. Refer to the sizing criteria below.

3. **Conveyance:**
   - o Landscape infiltration practices shall be designed off-line from the primary conveyance system.
   - o A flow splitter or other mechanism shall be used to divert storms larger than the WQ_v or Cp_v design storm around the practice to a stable, downstream conveyance system.
   - o Runoff shall enter, flow through, and exit landscape infiltration practices in a safe and non-erosive manner.
   - o Inflow may be conveyed via sheet flow, or via concentrated flow using depressed curbs with wheel stops, curb cuts, downspouts, storm drains, and catch basins.

4. **Layout, Dimensions, and Treatment Layers:**
   - o A 3- to 12-inch-deep surface ponding shall be provided.
   - o A surface mulch layer (2 to 3 inches thick) of shredded hardwood shall be provided to enhance plant survival and inhibit weed growth. Triple-shredded hardwood mulch exhibits the lowest propensity for floating compared to the other organic mulches. It also has a high carbon to nitrogen ratio which mitigates the potential of leaching nitrogen. In special situations, coir or jute matting, river stone, or pea gravel may be acceptable alternative. When stone is provided on the surface, the ponding depth shall be measured from the top

of the stone. In residential applications the temporary surface storage depth may generate the need for safety features.

- A bioretention soil media layer of at least 24 inches deep and no deeper than 48 inches shall be provided.
- A 6-inch layer of sand shall be provided below the bioretention soil media as an interface to the subsoil.
- The bioretention soil media, mulch, and bridging layer shall conform to the specifications found in Appendix I.
- Geotextile shall not be provided along the top, bottom, or between any horizontal layer. The use of geotextile along the sides of filter is optional.

5. **Underdrains, Cleanouts, and Observation Wells:**
   - A minimum of one observation well must be provided for every 1,000 ft2 of filter media surface area.
   - The top of the observation well shall extend at least 6 inches above ground and shall be protected by a cage or constructed of material resistant to breakage from lawn mowers.
   - No underdrain shall be provided.

6. **Sizing Criteria:**
   - At least 75% of the design runoff treatment volume (i.e., Cp_v or WQ_v) shall be provided as temporary ponding storage above the surface of the landscape infiltration practice. The top of the bioretention soil media is considered the surface.
   - Where a runoff volume greater than 2,000 ft^3 enters a landscape infiltration practice as concentrated flow from a pipe or channel, a forebay shall be provided as pretreatment and as a possible means for bypassing flows larger than the design volume away from the landscape infiltration filter. The forebay shall be sized to hold at least 10% of the runoff treatment volume (i.e., WQ_v or Cp_v). The forebay storage volume reduces the required above surface storage volume from 75% to 65%. Forebay volumes in excess of 10% shall not be considered as contributing to the provided storage volume.
   - The minimum allowable temporary surface ponding depth is 3 inches. The maximum allowable temporary ponding depth for both WQ_v and Cp_v is 12 inches. The ponding depth is measured from the top of the bioretention soil media. Where stone or gravel instead of mulch is provided on the surface, the ponding depth shall be measured from the top of the stone. In residential applications the temporary surface storage depth may generate the need for safety features.
   - At least 6 inches of freeboard shall be provided above the surface ponding design elevation.
   - Earthen side slopes of the surface ponding area shall no steeper than 2:1 (H:V) in cut and 3:1 (H:V) in fill and shall have a dense vegetative cover.
   - The filter surface area of the landscape infiltration practice (A_f) should occupy the entire bottom of the surface storage, except the side slopes and limited clearances. Where there is a justified reason for this not being possible, Equation 3.1 in the Section 3.1.4 shall be used to calculate the required filter bed area.

- o Landscape infiltration facilities shall be designed to fully dewater the entire design volume within 48 hours.

Landscape Plan:

1. Landscaping plans shall be provided according to the guidance in Appendix H. Plant tolerance to saturated and inundated conditions as well as drought shall be considered as part of the design. A dense and diverse planting plan will provide an aesthetically pleasing design, which will enhance property value and community acceptance.

Table 3.13 Summary of Design Elements for Landscape Infiltration Practices

Design Element	
Application	Used with new development and redevelopment Used to treat full or partial runoff for WQ_v and Re_v Used to treat full or partial runoff for Cp_v
Size Limitations	Use of landscape infiltration is limited to runoff treatment volumes ≤ 8,000 ft^3 for both WQ_v and Cp_v
On-line/Off-line	On-line allowed if concentrated runoff volume conveyed to practice ≤ 2,000 ft^3 On-line allowed if inflow is sheet flow Otherwise, practice must be off-line
Pre-treatment	When inflow is concentrated for storage volumes > 2,000 ft^3, a pre-treatment forebay is required Pretreatment forebay to be 10% of required landscape infiltration surface storage volume
Soil type	HSG A or B soils Infiltration rate of 0.52 inches per hour or greater
Groundwater	At least 4 ft below bottom of sand layer (2 ft for Eastern Shore)
Soils Investigation	One test pit or boring per 5,000 s.f. of surface area
Surface Storage Volume	75% of the design runoff treatment volume (i.e., WQ_v or Cp_v) Must fully dewater design volume within 48 hours
Surface Storage Side Slopes	Maximum 3:1 (H:V) for fill, no steeper than 2:1 (H:V) in cut. Stabilized vegetative cover on slopes
Ponding Depth	Minimum 3 inches Maximum 12 inches for WQ_v and Cp_v
Freeboard	Minimum 6 inches above design storage volume (i.e., 75%WQ_v or 75%Cp_v treatment volumes)
Filter Area	Landscape infiltration filter must cover entire bottom of surface storage area
Recharge	Re_v is limited by the drainage area to practice
Filter Media	Minimum 24 inches of bioretention soil media Minimum 6 inches of sand below bioretention soil media
Observation Wells	Minimum one per 1,000 ft^2 of filter area
Cleanouts	Observation well can function as a clean out

Design Element	
Surface Cover	Minimum 3 inches of mulch Only use shredded hardwood mulch since other types float In special situations, coir or jute matting, river stone, or pea gravel may be acceptable alternative
Vegetation	Follow landscaping guidance in Appendix H

Figure 3.10 Landscape Infiltration

(Page intentionally left blank for future detail)

3.1.3.6 Dry Wells

A dry well is a volume-based ESD practice that is created by having an excavated pit or structural chamber filled with gravel or stone to provide temporary storage and infiltration of stormwater runoff from rooftops. The storage area may be constructed as a shallow trench or a deep well. Rooftop runoff is directed to these practices to slowly infiltrate into the underlying soils prior to the next storm event. The pollutant removal capability of dry wells is directly proportional to the amount of runoff that is stored and allowed to infiltrate.

Function and Configuration:

Dry wells can be used in both residential and commercial sites and are limited to treating runoff from rooftops. Dry wells are not appropriate for treating runoff from large impervious areas. Successful application is dependent upon soil type and groundwater elevation.

When designed according to the guidance provided below, dry wells will provide treatment for the required WQ_v, Re_v, and Cp_v.

Site Conditions:

1. **Topography:** Steep terrain affects the successful performance of a dry well. Installation on slopes greater than 20% should be avoided.

2. **Soils and Groundwater:**
   - Permeable soils are critical to the successful application of dry wells. The HSG for underlying soils shall be A or B.
   - Dry wells located in HSG B soils (i.e., loams, silt loams) shall not exceed 5 feet in depth. Dry wells located in HSG A soils (i.e., sand, loamy sand, sandy loam) shall not exceed 12 feet in depth.
   - The depth from the bottom of a dry well to the seasonal high water table, bedrock, hard pan, or other confining layer shall be greater than or equal to 4 feet (2 feet on the Eastern Shore).

3. **Setbacks and Clearances:**
   - Dry wells should not be used in areas where their operation may create a risk for basement flooding, interfere with subsurface sewage disposal systems, or affect other underground structures.
   - Dry wells shall be located down gradient of building structures and shall be setback at least 10 feet from buildings, 50 feet from confined water supply wells, 100 feet from unconfined water supply wells, and 25 feet from septic systems.
   - Dry wells shall be setback a minimum of 100 feet from slopes of 15% and 200 feet from slopes of 25%.

4. **Hotspot Runoff:** Dry wells shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitation:**
   - Small drainage areas are most appropriate for dry well applications. Larger non-residential areas may be treated provided the dry well is sized according to the requirements for infiltration practices found in Section 3.3.
   - The drainage area to each dry well shall not exceed 1,000 ft2.
   - Drainage areas should be small enough to allow infiltration into the ground within 48 hours.

2. **Pretreatment:** Pretreatment measures shall be installed to allow filtering of sediment, leaves, or other debris. This may be done by providing gutter screens and a removable filter screen installed within the downspout pipe. The removable filter screen should be installed below the overflow outlet and easily removed so that homeowners can clean the filter.

3. **Conveyance:**
   - Rooftop runoff is collected through gutters and downspouts and discharged directly into a dry well. The gutter and downspout system shall be sized to adequately convey the design storm.
   - An overflow shall be provide to direct flows larger than the design storm away from the practice to an above ground splash pad and conveyed in a non-erosive manner to a stable outfall.

4. **Layout, Dimensions, and Treatment Layers:**
   - The stone or gravel media shall be composed of an 18 to 48-inch layer of clean washed, uniformly graded material (e.g., ASTM No. 57 stone or equal). A porosity of 0.40 shall be used in calculations.
   - A one-foot layer of sand shall be provided in the bottom of a dry well to allow for bridging between the existing soils and trench gravel.
   - Filter cloth shall not be installed on the bottom of the dry well.
   - Geotextile shall be used to line the top and sides of the dry well to prevent the pore space between the stones from being clogged by the surrounding native material.
   - The dry well underground chamber may be constructed as a subsurface prefabricated chamber.

5. **Underdrains, Cleanouts, and Observation Wells:**
   - A vertical observation well consisting of an anchored, 4 to 6-inch diameter pipe shall be required. The top of the observation well shall be at least six inches above grade. and shall be protected by a cage or constructed of material resistant to breakage from lawn mowers.

- A horizontal underground distribution pipe (4-to-6-inch diameter) shall be perforated to fill the trench along its entire length.

Sizing Criteria:

1. A dry well shall be designed to capture and store the design treatment volume (WQ_v or Cp_v). The storage area for the design treatment volume includes the stone fill and the sand and gravel layers in the bottom of the facility.

2. Storage calculations shall account for the porosity of the stone, gravel and sand media.

3. The length of a dry well should be longer than the width to ensure proper water distribution and maximize infiltration.

Landscape Plan:

1. A minimum one foot of soil cover shall be provided from the top of the dry well to the ground surface elevation. The soil should be stabilized with a dense cover of vegetation. In areas where frost heave is a concern, soil cover may need to be as much as four feet. In these cases, a geotechnical engineer should be consulted.

Table 3.14 Summary of Design Elements for Dry Wells

Design Element	
Application	Used with new development and redevelopment Used to treat full or partial runoff for WQ_v Re_v, and Cp_v
Drainage Area	Appropriate for small drainage areas DA to each drywell shall not exceed 1,000 ft^2 Small enough to allow infiltration into the ground within 48 hours
On-line/Off-line	Direct flows larger than the design storm away from the practice
Pre-treatment	Provide pretreatment such as gutter screens and removable filters installed below the overflow outlet
Soil type	HSG A or B Depth of trench bottom ≤ 5 feet in HSG B soils Depth of trench bottom ≤ 12 feet in HSG A soils
Groundwater	At least 4 ft below bottom of gravel layer (2 ft for Eastern Shore)
Storage Volume	Storage volume includes sand and gravel layers. Storage to account for porosity of the gravel and sand media
Filter Media	1 foot of sand in bottom as bridging layer between gravel and in situ soils
Distribution Pipe	4-to-6-inch diameter perforated pipe to fill the trench along its entire length
Observation Wells	One pipe with 4–6-inch diameter
Dimensions	The length of a dry well should be longer than the width

Figure 3.11 Dry Well

(Page intentionally left blank for future detail)

3.1.3.7 Pocket Submerged Gravel Wetlands

A pocket submerged gravel wetland is a small-scale, volume-based flow through treatment system with wetland plants rooted in a rock or gravel media. Runoff is temporarily retained on the surface above the wetland soil and then filtered through a saturated ("submerged") gravel substrate before discharging. A pocket submerged gravel wetland is a smaller version of the larger submerged gravel wetland structural practice described in Section 3.2.

Pocket submerged gravel wetlands treat stormwater runoff through attenuation, settling, filtration, physical and chemical adsorption, microbial transformation, and uptake. Settling of particulate matter occurs in the pretreatment forebay and above the wetland surface. Filtering and adsorption occur as stormwater runoff passes through the system. Biological uptake from algae and bacteria microbes growing within the gravel substrate removes additional pollutants.

The conversion and removal of nitrogen is dependent on aerobic conditions in the settling forebay and anerobic conditions in a subsurface treatment cell(s). Aerobic conditions are maintained when the forebay fluctuates between dry conditions and temporary ponding. Anaerobic conditions are maintained in the treatment cell(s) with saturated conditions from the high water table and slow flow through the gravel layer. This lowers the dissolved oxygen level to allow nitrate conversion to nitrogen gas.

Function and Configuration:

Pocket submerged gravel wetlands can provide treatment for WQ_v, Re_v, and Cp_v. This practice can be used in commercial and industrial projects but is not recommended for individual residential lots. The maximum runoff volume (i.e., WQ_v and Cp_v) that may be managed by this practice is 8,000 ft^3.

Stormwater runoff enters the surface of a pocket submerged gravel wetland via piped or overland flow. As the depth of storage increases above the surface, the hydraulic pressure forces runoff from previous storms that has been retained in the media below to filter through the gravel substrate and discharge through an underdrain collector pipe on the downstream end. The control of the discharge is set at 4 inches below the soil surface of the wetland. This keeps the gravel chamber and soil layer wet between storm events, which sustains the microbes as well as the wetland plants. As the retained runoff leaves the system, the ponded surface storage filters through pipe or stone chimneys to the gravel chamber below. After the surface storage has been drawn down, the water in the gravel substrate remains until the next storm event results in runoff ponding on the surface.

Site Conditions:

1. **Topography**: The surrounding local slopes should be <2% but with sufficient elevation drop to maintain positive drainage to and through the wetland media.

2. **Soils and Groundwater:**
   - Pocket submerged gravel wetlands are best suited for poorly drained soils or soils with high groundwater. The soils shall be HSG D or there shall be a high groundwater table, hard pan, or other confining layer present to maintain submerged (saturated) conditions.
   - A liner shall not be constructed for the purpose of creating saturated conditions in locations with HSG A, B, and C soils.
   - Soils investigations shall include at least one test pit or boring per 1 acre of site disturbance and shall be conducted in accordance with Appendix A.

3. **Setbacks and Clearances:**
   - Pocket submerged gravel wetlands should be located down gradient from building structures and setback at least 10 feet.
   - Pocket submerged gravel wetlands shall be located at least 30 feet from water supply wells and 25 feet from septic systems. If designed to provide recharge, then the practice shall be located at least 50 feet from confined water supply wells and 100 feet from unconfined water supply wells.
   - Pocket submerged gravel wetlands shall be sized and located to meet minimum local requirements for clearance from underground utilities.

4. **Hotspot Runoff:** To avoid groundwater contamination, pocket submerged gravel wetlands shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff.

Design Criteria:

1. **Drainage Area and Size Limitation:** The drainage area should be large enough to maintain saturated conditions based on a wetland draw down assessment and considering evapotranspiration losses as zero.

2. **Pretreatment:** Where a runoff volume greater than 2,000 ft^3 enters a pocket submerged gravel wetland as concentrated flow from a pipe or channel, a pretreatment forebay shall be provided. For nitrogen removal, the forebay should be designed to fully drain between storm events. Refer to sizing criteria.

3. **Conveyance:**
   - Runoff shall enter, flow through, and exit pocket submerged gravel wetlands in a safe and non-erosive manner.

- Inflow may be conveyed via sheetflow or concentrated flow using depressed curbs with wheel stops, curb cuts, downspouts, storm drains, and catch basins. Concentrated points of inflow shall be protected with energy dissipation.
- Flow into the pocket submerged gravel wetland (either directly into the gravel wetland area or from a forebay) shall be uniformly distributed across the width of the facility. A level edge or spreader between the forebay and the pocket submerged gravel wetland can be used to promote uniform distribution. When flow is piped, a slotted or perforated pipe (4 to 6-inch) with a horizontal distribution system is used to promote flow distribution.
- Concentrated runoff volume greater than 2,000 ft^3 shall be designed off-line from the primary conveyance system. A flow splitter or other mechanism shall be used to divert storms larger than the design storm around the practice in a safe and stable manner to a stable, downstream conveyance system.
- Infiltration through the soil layer cannot be the principal path into the gravel layer. A pipe chimney or stone chimney shall be provided at inflow points. Pipe and stone chimneys shall be at least 15 feet, but no more than 50 feet, from the outlet pipe. Stone chimneys should be 2-4 feet wide and begin at the top of the wetland soil layer. Suitable material such as geotextile should be provided along the sides of the stone chimney to prevent migration of the wetland soil into the stone. Pipe chimneys shall be a perforated pipe at least 6 inches in diameter and evenly spaced along the width of the facility.
- All discharges shall be to a stable outfall designed for non-erosive velocities for the design storm.

4. **Layout, Dimensions, and Treatment Layers:**
   - A 6- to 24-inch-deep surface ponding area shall be provided. The temporary surface ponding depth shall not be greater than the tolerance levels of the wetland vegetation (refer to Appendix H).
   - Earthen side slopes of the surface ponding area shall no steeper than 2:1 (H:V) in cut and 3:1 (H:V) in fill and shall have a dense vegetative cover.
   - An 8-inch deep wetland soil layer shall be provided.
   - A minimum 3-inch deep pea gravel bridging layer between the wetland soil layer and the gravel medium. This also functions as the interface between the stone chimney and the submerged gravel layer below.
   - A 18- to 48-inch deep gravel bed shall be provided. The gravel substrate shall be no deeper than 48 inches.
   - Geotextile shall not be provided along the top, bottom, or between any horizontal layer. The use of geotextile along the sides of gravel wetland is optional.

5. **Underdrain System, Cleanouts, and Observation Wells:**
   - The discharge from the pocket submerged gravel wetland is through an underdrain pipe collection system.

- The recommended configuration for the outlet pipe is a J-hook, adequately sized to avoid clogging. The control point of the outlet shall be set at an elevation 4 inches below the surface of wetland soil.
- The hydraulic control is in the form of a standpipe connected to the underdrain. The outlet control for the standpipe is just below the wetland surface. The system shall be configured so that flow exiting the pocket submerged gravel wetland must first traverse vertically and horizontally through the underground gravel substrate before it enters the underdrain pipe located at the bottom of the gravel substrate.
- In areas with very high groundwater, the design shall ensure that groundwater is not siphoned off by locating the invert of the outlet at least 6 inches above the seasonally high groundwater elevation.
- The diameter of the underdrain pipe shall be at least 4 inches.
- The invert of the underdrain pipe shall be 3 inches above the bottom of the gravel substrate.
- The underdrain shall not be wrapped in geotextile.
- A cleanout pipe shall be located at the upgrade end of each underdrain pipe run and also at every bend (i.e., T's and Y's). The length of pipe between cleanouts shall be no greater than 150 ft.
- A minimum of one observation well shall be provided for every 2,000 ft^2 of media area.
- The cleanout/observation well shall extend 6 inches above ground and shall be protected by a cage or constructed of material resistant to breakage.
- Provisions for draining the pocket submerged gravel wetland for maintenance shall be provided. The ability to drain the entire gravel treatment layer for maintenance using the control structure and outlet pipe is preferable. The outlet piping leading to the control structure should include an accessible gate valve or a removable cap provided for this purpose.
- Underdrains, cleanouts, and observation wells shall conform to the specifications found in Appendix I.

Sizing Criteria:

1. **Forebay:**
    - Where a runoff volume greater than 2,000 ft^3 enters a pocket submerged gravel wetland as concentrated flow from a pipe or channel, a forebay shall be provided as pretreatment.
    - The forebay can also be used to bypass flows larger than the design volume away from the gravel wetland area. The forebay shall be sized to hold at least 10% of the runoff treatment volume (i.e., WQ_v or Cp_v). The forebay storage volume reduces the required surface storage volume above the surface of the gravel wetland to 90%. Forebay volumes in excess of 10% shall not be considered as contributing to the provided storage volume.
    - The forebay shall be designed to completely drain between storm events. The forebay bottom elevation should be 3 to 6 inches higher than the surface of the gravel wetland area.

Alternatively, a deep sump concrete inlet or below ground pretreatment chamber may be used.

2. **Storage:**
   - **Surface Storage:**
     - The provided surface storage volume shall be equal to 100% of the design runoff treatment volume (i.e., Cp_v or WQ_v). The top of the wetland soil is considered the surface.
     - The minimum allowable ponding depth is 6 inches.
     - The maximum allowable ponding depth for the design volume is 24 inches. The ponding depth is measured from the top of the wetland soil.
     - At least 6 inches of freeboard shall be provided above the design storage volume elevation.
     - Note that the surface area requirements for stormwater wetlands in Chapter 3 do not apply to pocket submerged gravel wetlands or submerged gravel wetlands. The pollutant removal processes in stormwater wetlands and submerged gravel wetlands are different. Most of the pollutant removal in submerged gravel wetlands takes place within the gravel media.
   - **Media Storage:**
     - The storage provided in the voids of the pea gravel and gravel layers shall be equal to at least 100% of the design runoff treatment volume (i.e., Cp_v or WQ_v). A porosity of 0.40 shall be used in calculations.

3. **Length to Width Ratio:**
   - The flow path through the pocket submerged gravel wetland is referred to as the length. The width of the pocket submerged gravel wetland is the dimension perpendicular to the length and is the distance over which the inflow is dispersed.
   - The length to width ratio (L:W) shall be between 1:1 to 1:2 to spread the flow out along the width of the pocket submerged gravel wetland. This slows the flow, eliminates dead zones, and maximizes the treatment contact area.
   - To ensure a uniform distribution and to prevent short-circuiting, the width should not exceed 100 feet.
   - The flow length along the gravel media shall be at least 15 feet.
   - Multiple treatment "cells" may be used for meeting the L:W ratio. The "cells" should not necessarily be separated by earth berms or other impermeable divides. Their purpose is to provide multiple entry points into the subsurface treatment chamber, not divide the treatment chamber into isolated sections which could be starved of water during the smaller rain events.

Landscape Plan:

1. Aesthetically pleasing landscape designs generally enhance property value and community acceptance. Landscaping plans shall be provided according to the guidance in Appendix H.

Table 3.15 Summary of Design Elements for Pocket Submerged Gravel Wetland

Design Element	
Application	Used with new development and redevelopment Used to treat runoff for full or partial WQ_v, Re_v Re_v is provided unless there is a liner. Used to treat runoff for full or partial Cp_v, when the required Cp_v for discharge point from development site is ≤ 8,000 ft^3
Drainage Area and Size Limitations	The drainage area should be large enough to maintain saturated conditions Use of pocket submerged gravel wetland is limited to runoff design volume of ≤ 8,000 ft^3 for both WQ_v and Cp_v
On-line/Off-line	May be on-line when the runoff volume of ≤ 2,000 ft^3 enters the practice as concentrated flow Otherwise, practice must be off-line
Pre-treatment	When runoff volume > 2,000 ft^3 , a pre-treatment forebay is required
Soil type	HSG C or D soils (note all soil types located in high groundwater are classified as HSG D)
Groundwater	High groundwater required
Soils Investigation	One test pit or boring per 1 acre of site disturbance indicating groundwater elevation
Storage Volume	Surface Storage: 100% of the design runoff treatment volume (i.e., WQ_v or Cp_v) Media Storage: 100% of the design runoff treatment volume (i.e., WQ_v or Cp_v)
Side slopes	No steeper than 2:1 (H:V) in cut and 3:1 (H:V) in fill. Dense vegetative cover required on slopes
Ponding Depth	Minimum 6 inches Maximum 24 inches
Freeboard	Minimum 6 inches above design storage volume
Filter Media	Minimum 8 inches of wetland soil Minimum 3 inches of pea gravel as bridging layer Gravel layer ≥ 18 inches and ≤ 48 inches deep
Underdrain	Collection pipe with minimum 4-inch diameter with minimum 3 inches gravel below invert
Outlet	Outlet pipe (e.g., J-hook) set 4 inches below top of wetland soil and at least 6 inches above the seasonally high groundwater table

Design Element	
Observation Wells	Minimum one per 2,000 ft^2 of media area
Cleanouts	Provide at end of underdrain runs and at T's and Y's Maximum 150 ft pipe length between cleanouts
Vegetation	Follow landscaping guidance in Appendix H.

Figure 3.12 Pocket Submerged Gravel Wetland

(Page intentionally left blank for future detail)

3.1.4 Open Channel Practices

Vegetated open channels or swales can provide pollutant removal through filtering, sedimentation, biological uptake, and infiltration into the underlying soils. In addition to providing water quality treatment, some variations of open channels can provide channel protection, and all open channels provide stormwater conveyance.

There are three design variants covered in this section: grass swales, bioswales, and wet swales. Bioswales and wet swales are considered volume-based practices. The grass swale is considered an area-based practice. The function of each is dependent on in-situ soils, topography, and drainage characteristics.

Design types include:

- Grass swale
- Bioswale
- Wet swale

Drainage Area Considerations

Open channel practices are first and foremost linear stormwater conveyance systems. As linear conveyance systems, these practices can receive stormwater runoff through direct discharges from pipes and other conveyance systems, and also through sheet flow entering the channel along its length. Therefore, the total contributing drainage area to an open channel will cumulatively increase along the length of the swale.

Due to their conveyance function, open channel systems are the only ESD practice that can be designed on line, and receive and convey runoff from larger storm events through the practice.

Stormwater Management Function and Applicability

Open channel practices may be designed to provide WQ_v. Bioswales and Wet Swales may also be designed to provide Cp_v. These practices may be used to meet the Re_v if designed to infiltrate through the soil. Open channel systems shall not be designed to meet q_p or q_f requirements. However, for small development sites, linear quantity management may be provided by extending the channel.

Open channel practices are a preferred stormwater management practice for roads, highways, and other linear impervious surfaces. When used to manage stormwater runoff from linear impervious surface, these practices shall be combined with a separate facility to provide quantity management controls.

3.1.4.1 Grass Swale

The grass swale is an area-based shallow, broad, vegetated, open channel used for water quality treatment and groundwater recharge. As an area-based practice, grass swales are different from bioswales and wet swales in that they do not require a volume of stormwater runoff to be stored to achieve treatment. For this reason, no partial water quality or groundwater recharge credit is available for this practice, and grass swales must be designed to provide full water quality treatment using the following criteria.

Function and Configuration:

Grass swales are a preferred practice for providing water quality treatment for roadways and other linear sites. Grass swales may also be used to convey flows larger than water quality storm, but they do not provide channel protection (Cp_v) or quantity management (q_p or q_f). On small sites, it may be possible to provide linear quantity management by extending the length of the swale beyond the required length and adding a check dam for storage. This effectively creates a linear detention facility in series with the grass swale. The detention mechanism shall not interfere with the design functionality of the grass swale.

Site Conditions:

1. **Topography:** While some gradient is needed to provide positive drainage through the system, grass swales are most effective on sites with flat to gradual slopes. The maximum allowable longitudinal slope for a grass swale is 4%.

2. **Soils and Groundwater:** Grass swales may be used on sites with any type of underlying soil. Grass swales situated in HSG C and D soils require the incorporation of soil amendments to achieve greater runoff reduction. To keep the channel dry between storm events, the bottom of the grass swale shall not intercept the seasonally high groundwater.

3. **Setbacks and Clearances:** Because of their location along roadways and driveways, grass swales are susceptible to winter salt applications. Salt tolerant vegetation is therefore required. See Landscaping Section below.

4. **Hotspot Runoff:** Grass swales shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitation:** The maximum allowable contributing drainage area to a grass swale is five acres.

2. **Pretreatment:** Pretreatment in the form of a gravel diaphragm, 12-inch wide by 12–inch deep, shall be placed along the edge of the paved surface where runoff enters the grass swale.

3. **Conveyance:**
   - o Runoff shall enter the grass swale as lateral sheetflow. Concentrated inflow or flow from curb cuts is not permissible.
   - o Runoff shall enter, flow through, and exit grass swales in a safe and non-erosive manner
   - o Grass swales can be designed as on-line practices. When configured as such, this ESD practice shall be designed to safely convey the runoff from the 10-year 24-hour storm in a non-erosive manner and within the channel banks with a minimum of 6 inches of freeboard.

4. **Layout, Dimensions, and Treatment Layers:**
   - o A dense grass cover shall be provided for proper function.
   - o The channel bottom slope shall be less than or equal to 4%.
   - o The channel bottom width shall be between two and eight feet.
   - o The channel side slopes shall be no steeper than 3:1 (H:V) and no flatter than 4:1 (H:V).
   - o The length of the grass swale shall be at least as long as the linear impervious surface that it is treating. In cases where the grass swale treats a non-linear surface (a surface other than a roadway), the minimum length of flow within the channel from the lowest point of the non-linear surface to the end of the channel must be at least as long as the maximum length of flow over the impervious surface.

Sizing Criteria:

1. Grass swales are designed based on the peak flow rate for the water quality storm. NRCS WinTR-20 (or an equivalent model as approved by the approving agency) and the appropriate NOAA rainfall distribution shall be used to compute the peak discharge rate for designing a grass swale using a weighted curve number for the drainage area rather than the weighted direct runoff depth used to calculate the WQ_v.

2. Manning's Coefficient "n" value for grass swales shall be (MDOT SHA, 2023):
   - o For flow depths 4 inches and below: Manning's "n" = 0.15
   - o For flow depths (d) between 4 inches and 12 inches: "n" = 0.207 – (0.0145 × d)
   - o For flow depths greater than 12 inches: "n" = 0.033

3. The maximum flow depth for the peak discharge for water quality storm is 4 inches.

4. The maximum flow velocity for the water quality storm is 1 fps.

5. Grass swales shall be designed to safely convey the 10-year, 24-hour storm at a non-erosive velocity with at least six inches of freeboard. Refer to Appendix E for critical non-erosive velocities for the soil and vegetative cover provided.

Landscape Plan:

1. Designers should choose permanent grass species that can withstand both wet and dry periods as well as relatively high-velocity flows within the channel. For applications along roads and parking lots, salt-tolerant species should be chosen. Taller and denser grasses are preferred, though the species of grass is less important than good stabilization. Grass channels should be seeded (not sodded) at a density to achieve a 95% turf cover after the second growing season. Seeding establishes deeper roots, and sod may have muck soil that is not conducive to infiltration (Storey et al. 2009).

Table 3.16 Summary of Design Elements for Grass Swales

Design Element	
Application	Used with new development and redevelopment Used for conveyance and to treat full runoff for WQ_v and Re_v
Drainage Area	Maximum 5 acres
On-line/Off-line	May be on-line or off-line
Configuration	Flow to swale must be sheetflow Swale runs parallel to contributing drainage area
Pre-treatment	Gravel diaphragm along edge of paved surface
Soil type	Any HSG soil When in HSG C and D soils, incorporate soil compost amendments
Groundwater	At least below bottom of swale
Soils Investigation	USDA Soil Survey
Swale Length	At least as long as impervious area being treated
Flow Limits	Maximum flow velocity of 1 fps for water quality design storm Maximum flow depth of 4 inches for water quality design storm
Freeboard	Minimum 6 inches above 10-year 24-hour flow depth
Swale Dimensions	Bottom width between 2 and 8 feet Bottom slope 4% or less Side slopes no steeper than 3:1 (H:V) and no flatter than 4:1 (H:V)
Vegetation	Dense grass cover. Follow landscape guidance in Appendix H.

3.1.4.2 Bioswale

The bioswale is a linear micro-bioretention system with a contributing drainage area that increases along the length of the swale. Like the other bioretention variants, bioswales contain shallow landscaped areas that utilize vegetation, mulch, and engineered soil media to retain and treat runoff through settling, filtration, and biological and chemical transformation. Stormwater runoff is temporarily stored on the surface of the practice, filtered through a mulch layer and an underlying bioretention soil media layer composed of a mixture of sand, soil, and organic matter. Stormwater runoff then flows through a sand and pea gravel bridging layer followed by a second gravel layer that holds an underdrain. Filtered stormwater exits through this underdrain. When additional storage is provided in excess gravel below the underdrain, bioswales also provide groundwater recharge. Check dams or other impoundments are used to store runoff above the surface of the filter to allow time for the runoff to enter the filter system and prevent runoff from bypassing the filter.

Function and Configuration

The bioswale is a volume-based practice that can be used to meet WQ_v, Re_v, and Cp_v requirements. Bioswales can be used in new and redevelopment in commercial and industrial projects, as well as retrofits, and are particularly suitable along roadways, parking lots, driveways, and other linear applications.

The maximum design volume (i.e., WQ_v and Cp_v) that can be managed by this practice is 8,000 ft^3. Bioswales without underdrains automatically provide groundwater recharge. Bioswales with underdrains can provide recharge by providing storage in a gravel reservoir (sump) below the underdrain.

Bioswales may be designed as online practices to convey runoff from larger storm events, however q_p and/or q_f shall be managed separately from WQ_v or Cp_v. Bioswales shall not be designed to meet q_p and q_f requirements.

Site Conditions

1. **Topography:**
    - Care should be taken when using bioswales in rugged terrain. Steep slopes will increase velocity, erosion, and sediment deposition thus shortening the design life of the bioswale.
    - Bioswales shall have longitudinal slopes less than or equal to 4.0% measured along the channel bottom.
    - Check dams may be used to provide grade control in steeper applications.

2. **Soils and Groundwater:**
    - The bioswale can be used in all HSG soil types, however, when HSG C and D soils are present, an underdrain is required.
    - The bioswale is suited for use in areas with a low groundwater table.

- For bioswales with underdrains, the bottom of the bioswale (i.e., bottom of gravel layer) shall be located at least 2 feet above the seasonally high groundwater table (1 foot on the Eastern Shore).
- For bioswales without underdrains, the depth from the bottom of the sand bridging layer to the seasonally high groundwater table, bedrock, hard pan, or other confining layer shall be greater than or equal to four feet (two feet on the Eastern Shore).
- Soils investigations shall include at least one test pit or boring per 1 acre of site disturbance and shall be conducted in accordance with Appendix A. Elimination of the underdrain requires that underlying soils have an infiltration rate of 0.52 in/hr or greater. Bioswales without underdrains are more effective at removing pollutants and are therefore encouraged where feasible.

3. **Setbacks and Clearances:** Bioswales located along roadways and driveways can be damaged by off-street parking. They are also susceptible to winter salt applications, so salt tolerant vegetation is recommended.

4. **Hotspot Runoff:** Because of their function as a conveyance system, bioswales, even with enhanced soil media, shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff and may contaminate groundwater.

Design Criteria

1. **Drainage Area and Size Limitation:** While there is no drainage area limit, the design runoff treatment volume for a bioswale is limited to 8,000 ft^3. The same limit applies to both WQ_v and Cp_v.

2. **Pretreatment:**
   - Where a runoff volume greater than 2,000 ft^3 enters a bioswale as concentrated flow from a pipe or channel, a pretreatment forebay shall be provided.
   - Pretreatment storage can be obtained by providing check dams at pipe inlets and/or driveway crossings.
   - Where bioswales receive sheet flow directly from impervious surfaces, pretreatment shall be provided in the form of a shallow gravel trench or diaphragm to minimize clogging of the bioswale filter. The gravel diaphragm shall be placed along the edge of the paved surface where runoff enters the swale and shall be 12 inches wide by 12 inches deep.

3. **Conveyance:**
   - Runoff shall enter, flow through, and exit bioswales in a safe and non-erosive manner.
   - Inflow may be conveyed as sheetflow or concentrated flow via storm drainpipes, catch basins, depressed curbs with wheel stops, or curb cuts. Wherever possible, runoff entering the bioswale as lateral sheetflow should be promoted.

- When bioswales are proposed in curb and gutter road conditions, the discharge of runoff from the roadway should be diverted to the swale through a series of curb cuts or backless inlets. Concentrated points of inflow shall be protected from erosion using an energy dissipater (e.g., plunge pools or rip-rap).
- Runoff volumes larger than the 1-year 24-hr design storm shall be prevented from entering the bioswale filter.
- To avert short circuiting of inflow into the gravel and underdrain, inflow points protected with stone shall be designed to avoid cross connections with the underdrain gravel layer.

4. **Layout, Dimensions, and Treatment Layers:**
   - A 3- to 12-inch-deep surface ponding area shall be provided. The ponding depth is measured from the top of the bioretention soil media at the downstream end point of the swale. Where stone or gravel instead of mulch is provided on the surface, the ponding depth shall be measured from the top of the stone.
   - A surface mulch layer (2 to 3 inches thick) of shredded hardwood shall be provided to enhance plant survival and inhibit weed growth. Triple-shredded hardwood mulch exhibits the lowest propensity for floating compared to the other organic mulches. It also has a high carbon to nitrogen ratio which mitigates the potential of leaching nitrogen. In special situations, coir or jute matting, river stone, or pea gravel may be acceptable alternatives. When stone is provided on the surface, the ponding depth shall be measured from the top of the stone.
   - The bioswale filter is comprised of bioretention soil media at least 24 inches deep and no deeper than 48 inches.
   - A bridging layer of a minimum of 3 inches of sand and a minimum of 3 inches of pea gravel shall be placed between the bioretention soil media and the underdrain gravel layer.
   - Underdrain gravel layer at least 12 inches deep shall be provided and shall include a minimum of 3 inches of gravel above the underdrain pipe and a minimum of 3 inches below the pipe.
   - The gravel recharge reservoir shall be located below the invert of the underdrain to allow stored runoff to exfiltrate into the underlying soils without impeding drainage from the upper layers. The recharge reservoir should extend under the entire bottom of the filter area. Bioswales with impermeable liners or practices that are formed of concrete, brick, or other hard surfaces do not provide recharge.
   - When no underdrain is required, underdrain gravel is not necessary, and instead a 6-inch layer of sand shall be provided below the bioretention soil media as an interface to the subsoil. A recharge reservoir is not necessary for attaining recharge when there is no underdrain.
   - Geotextile shall not be provided along the top, bottom, or between any horizontal layer. The use of geotextile along the sides of filter is optional.
   - Bioswales shall have a bottom width between two and eight feet. The channel bottom slope shall be less than or equal to 4.0% measured along the channel bottom. The channel side slopes shall be no steeper than 3:1 (H:V) and no flatter than 4:1 (H:V).

- **Check dams:** An embankment or berm at the downstream end of the swale retains runoff within the swale allowing it time to enter the filter rather than running downstream. Management of WQ_v and Cp_v is dependent on the surface storage volume provided behind the check dam. Check dams are compatible with the swale's function as a conveyance system and can also be used to reduce channel slopes and to form pretreatment pools. Check dams may be constructed of compacted earth, concrete, wood, or other similar materials. Check dams shall be less than three feet in height measured from the upstream toe, notched to allow passage of larger storms, and anchored into the side of the swale to prevent bypass of flows, erosion, and outflanking. Plunge pools or other energy dissipation may be required where the elevation difference between the top of the weir to the downstream channel invert is potentially erosive.

5. **Underdrains, Cleanouts, and Observation Wells:**
   - An underdrain system shall be provided for bioswales located in HSG C or D soils. For locations with HSG A and B soils, groundwater recharge should be promoted, and an underdrain should be discouraged.
   - The underdrain shall be sized so that the surface storage and media storage fully drain within 48 hours. The diameter of underdrain shall be at least 4 inches.
   - The preferred slope of the underdrain is 0.5%.
   - The underdrain shall not be wrapped in geotextile.
   - A cleanout pipe shall be located at the upgrade end of each underdrain run and also at every bend (i.e., T's and Y's). The length of pipe between cleanouts shall be no greater than 150 ft.
   - A minimum of one observation well shall be provided for every 2,000 ft^2 of filter surface. The observation well and cleanout can be combined.
   - The top of the cleanout/observation shall extend at least 6 inches above ground and shall be protected by a cage or constructed of material resistant to breakage from lawn mowers.
   - Underdrains, cleanouts, and observation wells shall conform to the piping specifications found in Appendix I.

Sizing Criteria:

1. At least 75% of the design runoff treatment volume (i.e., Cp_v or WQ_v) shall be provided as temporary ponding storage above the surface of the bioswale. The top of the bioretention soil media is considered the surface of the filter.

2. A forebay used for pretreatment shall be sized to hold at least 10% of the runoff treatment volume (i.e., WQ_v or Cp_v). The forebay storage volume reduces the required surface storage volume above the surface from 75% to 65%. Forebay volumes in excess of 10% shall not be considered as contributing to the provided storage volume.

3. Storage within the bioswale filter media does not contribute toward satisfying the required surface storage.

4. Bioswales shall be designed to safely convey the 10-year, 24-hour storm at a non-erosive velocity with at least six inches of freeboard. Refer to Appendix E for critical non-erosive velocities for the soil and vegetative cover provided.

5. The required surface area of the bioswale filter shall be sized based on the principles of Darcy's Law and computed using the following equation:

$$Af = (V) \times df) / (k \times (hf + df) \times tf) \qquad \text{(Equation 3.1)}$$

where:

A_f	=	required surface area of filtering media (ft^2)
V	=	100% of WQ_v or Cp_v runoff treatment volume (ft^3)
d_f	=	filtering media depth (ft)
k	=	coefficient of permeability of bioretention soil media = 1.0 ft/day (Virginia 2024)
h_f	=	Ave. height of water above filtering media (ft). (approx. ¼ max. ponding depth at the end of swale.
t_f	=	filtering media drain time = 2 days

6. The provided recharge volume is equal to the volume below the underdrain outflow invert multiplied by a porosity of 0.4. The credited recharge volume cannot be larger than the runoff to the BMP for the water quality storm (i.e., WQ_v to the BMP). Because the WQ_v and Cp_v sizing are based on surface storage and filter area, and recharge reservoir is separate from the bioretention process, the recharge volume is not included in the provided WQ_v and Cp_v calculations.

7. The maximum allowable ponding depth for WQ_v and Cp_v at the downstream end point of the swale is 12 inches.

Landscape Plan:

1. A dense vegetative cover shall be provided for proper function. Landscaping plans shall be provided according to the guidance in Appendix H. Vegetation is critical to the function and appearance of any bioretention system. Native and adapted plants are preferred; more hardy and usually require minimal nutrient or pesticide application. Aesthetically pleasing landscape designs generally enhance property value and community acceptance.

Table 3.17 Summary of Design Elements for Bioswales

Design Element	
Application	Used with new development and redevelopment Used for conveyance and to treat full or partial WQ_v, Re_v, and Cp_v Shall not be used to provide q_p or q_f
Sizing Limitations	Use of bioswales is limited to runoff treatment volumes of ≤ 8,000 ft^3 for both WQ_v and Cp_v
On-line/Off-line	On-line and off-line allowed Prevent runoff volumes larger than the 1-yr, 24-hr design storm from entering filter
Pre-treatment	When concentrated runoff volume > 2,000 ft^3, pre-treatment forebay required Pretreatment forebay to be 10% of required surface storage volume Gravel diaphragm along edge of paved surfaces
Soil type	Any HSG soil In HSG C and D soils, underdrain is required In HSG A and B soils with infiltration rate of at least 0.52 in/hr underdrain is not required and is discouraged
Groundwater	For bioswales with underdrains, at least 2 ft below bottom of gravel layer (1 ft for Eastern Shore) For bioswales without underdrains, at least 4 ft below bottom of sand layer (2 ft for Eastern Shore)
Soils Investigation	One test pit or boring per 1 acre of site disturbance For bioswales with no underdrain, one infiltration test per 5,000 ft^2 of surface area
Surface Storage Volume	75% of the design runoff treatment volume (i.e., WQ_v or Cp_v) 65% when a forebay is used to provide 10%
Surface Ponding Depth	Minimum 3 inches Maximum 12 inches for WQ_v and Cp_v at downstream end
Filter Area	Bioswale filter area must cover the entire bottom of the surface storage area
Freeboard	Minimum 6 inches above 10-year flow depth
Recharge Sump	Bioswales without underdrains intrinsically provide recharge For bioswales with underdrains, gravel reservoir below underdrain outflow invert must be ≥ required Re_v Porosity of gravel media = 0.4
Filter Media	Minimum 24 inches of bioretention soil media For bioswales with underdrain:

Design Element	
	o Bridging layer of minimum 3 inches of sand and minimum 3 inches of pea gravel o Minimum 10 inches of gravel (minimum 3 inches above and below underdrain) For bioswales without underdrain: o Minimum 6 inches of sand below bioretention soil media
Swale Dimensions	Bottom width between 2 and 8 feet Bottom slope 4% or less Side slopes no steeper than 3:1 (H:V) and no flatter than 4:1 (H:V)
Vegetation	Follow landscaping guidance in Appendix H Turf grass cover preferred on side slopes

Figure 3.13 Bioswale

(Page intentionally left blank for future detail)

3.1.4.3 Wet Swale

The wet swale is a linear pond system with a contributing drainage area that increases along the length of the swale. Wet swales combine components and functions of a swale, a wetland, and a wet extended detention pond to filter and treat runoff within a stormwater conveyance system. Linear on-line or off-line cells may be designed within an open channel to intercept groundwater and retain runoff to create saturated soil or shallow standing water conditions that can maintain wetland vegetation. The saturated soil and wetland vegetation provide the environment for settling, biological uptake, and microbial activity. Check dams or other impoundments are used to create storage in the swale.

Function and Configuration:

The wet swale is a volume-based practice that can be used to meet the WQ_v, Re_v, and Cp_v requirements. Wet swales can be used for new and redevelopment in commercial and industrial projects, and are particularly suitable along roadways, parking lots, and driveways. The maximum runoff treatment volume (i.e., WQ_v and Cp_v) that can be managed by this practice is 8,000 ft^3. Wet swales automatically provide groundwater recharge.

Wet swales may be designed as an on-line practice to convey runoff for larger storm events, however q_p and q_f shall be managed separately. Wet swales shall not be designed to meet q_p or q_f requirements.

Site Conditions

1. **Topography:**
   - Care should be taken when using wet swales in steep terrain. Steep slopes will increase velocity, erosion, and sediment deposition thus shortening the design life of the wet swale.
   - Wet swales shall have longitudinal slopes less than or equal to 4.0% as measured from the channel bottom.
   - Check dams may be used to provide grade control in steeper applications.

2. **Soils and Groundwater:**
   - Wet swales are best suited for HSG C or D soils.
   - Wet swales shall be installed in areas with a high groundwater table. If the seasonally high groundwater is not sufficiently high to maintain wet conditions, a bioswale is more appropriate.
   - Soils investigations shall include at least one test pit or boring per 1 acre of site disturbance and shall be conducted in accordance with Appendix A.

3. **Setbacks and Clearances:** Wet swales located along roadways and driveways can be damaged by off-street parking and are susceptible to winter salt applications, therefore salt tolerant vegetation is recommended.

4. **Safety and Access:** Wet swales are not recommended for high density residential developments due to the potential for safety concerns.

5. **Hotspot Runoff:** Because of their function as a conveyance system and providing groundwater recharge, wet swales shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitation:** The use of wet swales is limited to runoff treatment volumes of ≤ 8,000 ft^3 for both WQ_v and Cp_v

2. **Pretreatment:**
   - Where a runoff volume greater than 2,000 ft^3 enters a wet swale as concentrated flow from a pipe or channel, a pretreatment forebay shall be provided. Refer to the sizing criteria section below.
   - Where wet swales receive sheetflow directly from impervious surfaces, pretreatment shall be provided in the form of a shallow gravel trench or diaphragm to minimize clogging. The gravel diaphragm shall be placed along the edge of the paved surface where runoff enters the swale and shall be 12 inches wide by 12 inches deep.

3. **Conveyance:**
   - Runoff shall enter, flow through, and exit wet swales in a safe and non-erosive manner.
   - Inflow may be conveyed via sheetflow or concentrated flow via storm drain pipes, catch basins, depressed curbs with wheel stops, curb cuts, or other stable means. When wet swales are proposed in curb and gutter road conditions, the discharge of runoff from the roadway should be diverted to the swale through a series of curb cuts or backless inlets.
   - Concentrated points of inflow shall be protected with an energy dissipater (e.g., plunge pools or riprap).

4. **Layout, Dimensions, and Treatment Layers:**
   - Wet swales shall be designed with permanent wet storage for treating WQ_v and dry storage for slow release of the Cp_v. The permanent wet pool shall intercept the seasonally high groundwater table. The Cp_v outlet control shall be located above the groundwater elevation to avoid siphoning of groundwater.
   - A 3- to 12-inch-deep temporary surface ponding area shall be provided above the wet pool elevation. The minimum allowable temporary surface ponding depth is 3 inches. The maximum allowable temporary surface ponding depth above the wet pool elevation is 12 inches. The ponding depth is measured at the downstream end point of the swale.
   - The wet pool depth shall be at least as deep as the temporary surface ponding depth, as measured at the downstream end point of the swale.

- Slow release of the Cp_v requires an outlet with a small cross-sectional area. Small diameter orifices are highly susceptible to clogging. Orifice diameters smaller than 3 inches shall be equipped with an anti-clogging device. In no case shall the diameter be smaller than 1 inch. V-notch weirs are more effective for low flows, attaining the design angle requires more oversight during construction.
- Wet swales shall have a bottom width between two and eight feet. The channel bottom slope shall be less than or equal to 4.0%. The channel side slopes shall be no steeper than 3:1 (H:V) and no flatter than 4:1 (H:V).
- **Check dams:** An embankment or berm at the downstream end of the swale retains runoff within the swale. A check dam together with a control structure, such V-notch, orifice, standpipe, or riser, allows for a permanent wet pool as well as temporary storage above the wet pool. Check dams are compatible with the swale's function as a conveyance system and can also be used to reduce channel slopes and to form pretreatment pools. Check dams may be constructed of compacted earth, concrete, wood, or other similar materials. Check dams shall be less than three feet in height measured from the upstream toe. Check dams shall be anchored into the side of the swale to prevent bypass of flows and erosion. Plunge pools or other energy dissipation may be required where the elevation difference between the top of the weir to the downstream channel invert is potentially erosive.

Sizing Criteria:

1. When the runoff volume is greater than 2,000 ft^3 and enters a wet swale as concentrated flow from a pipe or another channel, a forebay shall be provided as pretreatment. The forebay shall be sized to hold at least 10% of the runoff treatment volume (i.e., WQ_v or Cp_v). The forebay storage volume reduces the required storage volume in the main swale. Forebay volumes in excess of 10% shall not be considered as contributing to the provided storage volume.

2. Wet swales shall be designed with a permanent wet pool equal to at least 100% of the WQ_v. Cp_v runoff treatment volume is managed by providing extended detention storage above the wet pool for slow release. Where wet swales are designed to manage Cp_v and the provided extended detention volume is greater than 50% of the WQ_v runoff treatment volume, the required permanent wet pool storage may be reduced to 50% of the WQ_v runoff treatment volume.

3. The extended detention storage volume provided in wet swale designed to manage Cp_v shall be at least 62% of the Cp_v runoff treatment volume in all watersheds except Use Class III/IV, and at least 56% for wet swales located in Use Class III/IV watersheds.

4. Swales shall be designed to safely convey the 10-year, 24-hour storm at a non-erosive velocity with at least six inches of freeboard. Refer to Appendix E for critical non-erosive velocities for the soil and vegetative cover provided.

5. Wet swales with impermeable liners or practices that are formed of concrete, brick, or other hard surfaces do not provide recharge.

Landscape Plan:

1. Landscaping plans shall specify proper grass or wetland plantings based on the design variant chosen and anticipated hydrologic conditions along the channel (see Appendix H). If the wet pool volume is less than 6 inches, wetland plantings should be provided in accordance with Appendix H. Native species are best for survival and enhancing bio-diversity and wildlife. A thick vegetative cover shall be provided on the side slopes above the ponding elevation. Wet swales, employing wetland vegetation or other low maintenance ground cover do not require frequent mowing of the channel.

Table 3.18 Summary of Design Elements for Wet Swales

Design Element	
Application	Used with new development and redevelopment Used for conveyance and to treat runoff for full or partial WQ_v, Re_v, and Cp_v
Sizing Limitations	Use of wet swales is limited to runoff volumes of ≤ 8,000 ft^3 for both WQ_v and Cp_v
On-line/Off-line	On-line and off-line allowed
Pre-treatment	When concentrated runoff volume > 2,000 ft^3, pre-treatment forebay required Pretreatment forebay to be 10% of required surface storage volume Gravel diaphragm along edge of paved surfaces
Soil type	HSG C or D soils (note all soil types located in high groundwater are classified as HSG D)
Groundwater	High groundwater required
Soils Investigation	One test pit or boring per 1 acre of site disturbance
Storage Volume	Permanent wet pool ≥ 100% WQ_v runoff treatment volume where there is no extended detention storage Permanent wet pool ≥ 50% WQ_v runoff treatment volume if extended detention storage ≥ 50%WQ_v Extended detention storage above permanent pool elevation ≥ 62%Cp_v of runoff treatment volume for all watersheds except Use Class III/IV and ≥ 56%Cp_v for Class III/IV watersheds.
Ponding Depth	Temporary ponding depth above permanent wet pool: minimum 3 in and maximum 12 in Permanent wet pool depth: minimum ≥ temporary ponding depth and no maximum
Freeboard	Minimum 6 inches above 10-year flow depth
Swale Dimensions	Bottom width between 2 and 8 feet Bottom slope 4% or less Side slopes no steeper than 3:1 (H:V) and no flatter than 4:1 (H:V)
Vegetation	Follow landscaping guidance in Appendix H Turf grass cover on side slopes

Figure 3.14 Wet Swale

(Page intentionally left blank for future detail)

3.2 Structural Practices

Structural practices are larger and broader in their application than ESD practices. All structural practices except rainwater harvesting can remove pollutants through a combination of retention and settling, vegetative uptake, infiltration, and filtration. Structural practices can be located in-line with the primary conveyance system to provide flood protection for larger storm events. Most structural practices have additional design requirements beyond those for ESD practices including more stringent requirements for soils testing, freeboard, outlet control structures, construction specifications, safety features, and maintenance. Structural practices are grouped by the following:

- Stormwater Ponds
- Stormwater Wetlands
- Stormwater Infiltration
- Stormwater Filtering Practices

For new development projects, the use of structural practices is limited to managing Cp_v, q_p, and q_f,. A structural practice shall be used to manage the Cp_v when the Cp_v runoff volume for the discharge point from the development site is greater than 8,000 ft^3. In some situations, structural filtering practices can be used to manage the water quality volume for redevelopment. In these applications, the q_p, and q_f management shall be provided as storage above the WQ_v surface storage.

3.2.1 Stormwater Ponds

Stormwater ponds are designed to capture, store, and attenuate runoff primarily for the purpose of flood protection. Gradually release flow downstream reduces peak discharge rates and mitigates flooding. Using extended detention stormwater ponds can also be designed to provide the slow release necessary for channel protection. Ponds with permanent wet pools can provide water quality treatment through settling, biological uptake, and chemical processes.

A stormwater pond uses an embankment, a control structures (such as a riser or weir wall) with various outflow openings, and a spillway (such as a pipe or outlet channel) to provide storage at specified elevations for different design storms. Stormwater ponds can incorporate micro-topography, internal berms, and channels to create internal features such as forebays, micro-pools, and multiple treatment cells. Plantings, vegetation, and permanent wet pools also provide aesthetic, recreation, and wildlife habitat co-benefits.

The size and shape of stormwater ponds varies depending on the topography, runoff conveyance into the pond, the volume and depth of permanent and temporary storage, the rate of discharge and the type of outlet, vegetation, and landscaping.

Design types include:

- Wet pond
- Dry pond

Function and Configuration:

Stormwater ponds fall into two primary types: wet ponds and dry ponds. Wet ponds, also known as retention ponds, maintain a permanent pool of water. Dry ponds are dry except during and after a storm event. Both pond types can be designed with temporary detention storage for channel protection and flood control. Storage provided for channel protection is referred to as extended detention because it is released slowly.

Wet ponds can provide WQ_v and Re_v but may only be used for WQ on redevelopment projects. Permanent wet storage in an underground extended detention practice may not be used for managing the WQ_v. Wet ponds can be designed with extended detention and detention storage above the permanent wet pool elevation to manage Cp_v, q_f, and q_p. Extended detention storage volume is provided to manage Cp_v, and detention storage volume is provided to manage q_f, and q_p.

Dry ponds, including underground storage facilities, can be designed with extended detention storage to manage Cp_v and/or detention storage to manage q_f and q_p.

Stormwater ponds may be used to provide extended detention volume for Cp_v only where the required Cp_v runoff volume for the discharge point from the development site is greater than 8,000 ft^3. Due to practical orifice sizing limitations, a stormwater pond may not be used to manage a Cp_v runoff treatment volume less than 8,000 ft^3.

Site Conditions

1. **Topography:**
   - For all ponds, construction on steep slopes will require higher embankments which may impact hazard classification.

2. **Soils and Groundwater:**
   - Wet Ponds:
     - Wet ponds require a permanent pool. The source of the wet pool can be groundwater or surface water. Where a permanent pool is sustained through surface water, there is a minimum drainage area requirement.
     - Wet ponds without adequate ground water to sustain the required permanent pool level may require a liner.
   - Dry Ponds:
     - No specific criteria

3. **Setbacks and Clearances:**
   - A minimum non-woody vegetation buffer or setback shall be provided around the pond that extends 15 feet from the upstream and downstream toes of embankment, 15 feet from the spillway, and 25 feet around the control structure, or as required by MDE dam safety criteria.

4. **Safety and Access:**
   - o Fencing of ponds is not generally desirable but may be required by the local review authority.
   - o Benches and grading can be used to eliminate drop-offs and other safety hazards (see below for design requirements for benches).
   - o Warning signs prohibiting swimming and skating should be posted.
   - o Endwalls above pipe outfalls greater than 48 inches in diameter shall be fenced to prevent falls.
   - o The pond control structure shall be located within the embankment to facilitate maintenance access.
   - o The pond control structure openings shall not permit unauthorized access. Access to the pond control structure shall be provided by lockable covers and steps located within easy reach of valves and other controls.
   - o Control structure tops that are four feet or greater above the ground shall include railings or fencing for safety.
   - o A maintenance right-of-way or easement shall extend to all ponds from a public or private road.
   - o Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
   - o The maintenance access should extend to the embankment, forebay, pond area, control structure, emergency spillway (if applicable), and pond outfall.

Design Criteria:

1. **Drainage Area and Size Limitation:**
   - o Wet Ponds:
     - Wet ponds shall have a minimum contributing drainage area of ten acres or more unless groundwater is confirmed as the primary water source to sustain the permanent pool level.
   - o Dry Ponds:
     - There are no drainage area limitations for dry pond variants.

2. **Pretreatment:**
   - o Ponds should have sediment forebays or equivalent upstream pretreatment.
   - o A forebay shall be provided at each inlet, unless the inlet provides less than 10% of the total design storm inflow to the pond.
   - o The forebay shall consist of a separate cell, formed by an acceptable barrier such as an internal berm.
   - o The forebay storage volume shall be equal to or greater than 0.1 inch per impervious of contributing drainage.
   - o Exit velocities from forebays shall be non-erosive.

- A fixed vertical sediment depth marker should be installed in the forebay to measure depth of sediment deposition over time.

3. **Conveyance**
   - Stormwater runoff shall enter the stormwater pond in a non-erosive manner.
   - Inflow protection is required for all inflow pipes and channels.
   - Inflow pipes should not be fully submerged at normal pool elevations.
   - Outfall protection is required for all pond discharge points. A stilling basin or other outlet protection should be used to reduce flow velocities from the principal spillway to non-erosive velocities (see Appendix E for critical non-erosive velocities for grass and soil).
   - The channel immediately below the pond outfall may need to be modified to prevent erosion and to conform to natural dimensions in the shortest possible distance, typically by use of large riprap placed over geotextile.
   - Spillway pipes that discharge to a waterway, should be fitted with a flared pipe section (or other non-erosive treatment) that terminates at or near a stream invert or into a step-pool arrangement. Refer to MDE's waterway construction permit requirements for design criteria associated with impacts to waters of the state or non-tidal wetlands.
   - The design of stormwater ponds that discharge directly to tidally influenced waters, floodplains, streams, or closed stormwater conveyance systems shall include a hydraulic analysis of the effect of tailwater conditions on the conveyance of the design storm.

4. **Layout, Dimensions, and Treatment Layers**
   - Flow Paths and Microtopography:
     - For wet ponds, flow paths from inflow points to outlets shall be maximized. Ponds with a length to width ratio of 1.5:1 and ponds that are irregular in shape are recommended.
     - For wet ponds, water quality performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flow paths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of permanent pool, extended detention, and wetland).
     - All ponds can be designed with variations in bottom level and with internal berms to facilitate multiple cell functionality and application.
   - Side Slopes:
     - Internal side slopes for ponds shall be no steeper than 3:1 (H:V).
     - For wet ponds, internal side slopes should terminate on a safety bench (see criteria below).
     - Embankment side slopes shall be no steeper than 3:1 (H:V).
     - Embankments with access roads shall be designed with a minimum top width of 10 feet to accommodate maintenance equipment.
   - Pond Benches for Wet Ponds:
     - Pond benches shall be required for all wet ponds with a permanent pool depth four feet or deeper, unless the internal side slopes are 4:1 or flatter. The perimeter of the deep wet pool areas shall be surrounded by two benches (safety bench and aquatic bench) with a combined minimum width of 17 feet:

- Safety bench: A relatively flat bench shall be provided starting at 1 foot above the permanent pool design elevation and extending down to the permanent pool elevation. The bench shall have a maximum slope of 2 % toward the normal pool. The bench shall have a 12-foot minimum width and shall be stabilized with vegetation. The bench shall extend around the entire perimeter of the pond.
- Aquatic bench: A five-foot wide aquatic bench shall be provided starting at 1 foot below the normal pool elevation. This bench shall be on a maximum 2 % slope. This bench shall be planted with appropriate wetland vegetation. (See Appendix H). The aquatic bench shall extend around the entire perimeter of the permanent pool. An aquatic bench is not required in forebays.

o Principal Spillway and Control Structure:
  - The minimum control structure opening diameter shall be 3 inches and shall be adequately protected from clogging by an acceptable external trash rack. This opening size limit may be reduced to one inch if an internal orifice with exterior protection is provided (e.g., internal orifice inside perforated vertical standpipe protected by a hardware cloth and stone filtering jacket.) The use of a horizontal perforated pipe protected by geotextile and gravel for low flow anti-clogging is not recommended. Vertical pipes may be used as an alternative if a permanent pool is present. (See Appendix D).
  - For wet ponds, the preferred anti-clogging method for a low flow orifice is a submerged reverse-slope pipe that extends downward from the riser to an inflow point one foot below the normal pool elevation.
  - Alternative anti-clogging methods include using a broad crested rectangular weir with a notched or round opening, protected by a half-round corrugated metal pipe (CMP) or similar device that extends at least 12 inches below the normal pool.
  - All joints and pipe openings through the walls of the control structure shall be completely watertight.

o Appurtenances
  - Wet Ponds: All wet ponds shall have a pond drain that can completely drain the pond within 24 hours. This requirement is waived for the Eastern Shore where positive drainage is difficult to achieve due to very low relief.
    - ➢ The pond drain should be sized one size greater than the required drainpipe opening diameter.
    - ➢ All drains shall be equipped with an adjustable valve located within the control structure. The valve control shall be located at a point where it will not normally be inundated and can be easily accessed and operated in a safe manner. Typically a gate valve is used that is activated by a gate attached to a valve stem and hand wheel extending to near the top of and anchored to the control structure.
    - ➢ To prevent vandalism, the handwheel should be chained to a ringbolt, manhole step or other fixed object.

Sizing Criteria:

1. **Wet Ponds (Including Wet Extended Detention Ponds and Wet Detention Ponds):**
   - Wet ponds are designed to maintain a permanent wet pool. When providing WQ_v for redevelopment, 100% of the WQ_v runoff treatment volume shall be provided in the wet pool. This volume can be reduced for ponds also providing extended detention.
   - The required WQ_v storage volume may be reduced by the forebay storage, however forebay volumes in excess of 0.1 inch per acre of impervious area shall not be considered as contributing to the provided storage volume.
   - For wet extended detention ponds, up to 50% of the WQ_v runoff treatment volume may be provided as extended detention storage.
   - Cp_v is managed in a wet pond through extended detention. Extended detention storage shall be provided above the permanent wet pool. The extended detention storage is the volume required to temporarily store the runoff from the 1-year, 24-hour storm adjusted for climate change and discharge it over 36 hours (18 hours for Use Class III/V watersheds). The discharge is controlled by a low flow orifice. The extended detention storage volume shall be at least 62% of the Cp_v runoff treatment volume in all watersheds except Use Class III/IV, and at least 56% of the Cp_v runoff treatment volume for ponds located in Use Class III/IV watersheds.
   - Management of q_p and q_f is provided in a stormwater pond through detention. Refer to Appendix J.
   - The storage volume provided in a permanent wet pool does not contribute to managing q_p or q_f.
   - When managing q_p and/or q_f, detention storage shall be provided above the permanent wet pool. When a pond manages q_p and/or q_f in addition to the Cp_v, the hydraulic routing may include the extended detention volume.

2. **Dry ponds (Including Dry Extended Detention Ponds, Dry Detention Ponds, and Underground Storage):**
   - Cp_v is provided in a dry pond through extended detention. The extended detention storage is the volume required to temporarily store the runoff from the 1-year, 24-hour storm adjusted for climate change and discharge it over 36 hours (18 hours for Use Class III/V watersheds). The discharge is controlled by a low flow orifice. The extended detention storage volume shall be at least 62% of the Cp_v runoff treatment volume in all watersheds except Use Class III/IV, and at least 56% of the Cp_v runoff treatment volume for ponds located in Use Class III/IV watersheds.
   - Management of q_p and q_f is provided in a stormwater pond through detention. Refer to Appendix J.
   - When managing q_p and/or q_f, detention storage shall be provided above the permanent wet pool. When a pond manages q_p and/or q_f in addition to the Cp_v, the hydraulic routing may include the extended detention volume.

Landscaping Plan:

1. A landscaping plan for a stormwater pond and its buffer shall be prepared to indicate how aquatic and non-aquatic areas will be planted and stabilized. Landscaping guidance for stormwater ponds is provided in Appendix H.

2. It is desirable to locate forest conservation areas adjacent to ponds to encourage wildlife habitat connectivity and shading. To discourage resident geese populations, the buffer can be planted with trees, shrubs and native ground covers

3. Woody vegetation shall not be allowed within 15 feet of the upstream and downstream toes of embankment, 15 feet of the spillway, or 25 feet around the control structure, or as required by MDE dam safety criteria.

4. Wherever possible, plants that can withstand permanent or varying water elevations should be encouraged in a stormwater pond design, either along the aquatic bench (fringe wetlands), the safety bench and side slopes (emergent wetlands) or within shallow areas of the pool itself. The best elevations for establishing wetland plants, either through transplantation or volunteer colonization, are within six inches of the normal pool. Refer to Appendix H.

Table 3.19 Summary of Design Elements for Wet Ponds (with and without Extended Detention and Detention)

Design Element	
Application	Used to treat runoff for full or partial WQ_v for redevelopment Used to treat runoff for full or partial Cp_v where required Cp_v for discharge point is > 8,000 ft^3 Used to manage q_p and q_f for new development Used to manage q_p and q_f for redevelopment (if required)
Drainage Area	Minimum 10 acres unless groundwater or surface flow with a liner can maintain permanent pool
Conveyance	On-line or off-line as needed for design Safely pass the 10-year, 24-hour storm or as required by MDE dam safety criteria
Pre-treatment	Forebay required at every inlet that contributes 10% or more of total design storm inflow to pond Minimum forebay volume ≥ 0.1 inch per acre of impervious drainage area.
Soil type	All soil types
Groundwater	Design considerations but no limits
Soils Investigation	USDA Soil Survey and one test pit or boring in pond area indicating groundwater elevation or as required by MDE dam safety criteria
Storage Volume	Wet pond without extended detention: • 100%WQ_v runoff treatment volume in wet pool Wet pond with extended detention: • 62% or 56% Cp_v runoff treatment volume as extended detention storage above wet pool • 50%WQv* as extended detention storage above wet pool • Minimum Cp_v runoff treatment volume of 8,000 ft^3 • 50%WQ_v* storage in wet pool *Refer to limitations in narrative Routing of detention volume for q_p and q_f may include extended detention volume
Side slopes and Benching	Internal and external embankment side slopes no steeper than 3:1 (H:V) or as required by MDE dam safety criteria Benching required when permanent pool ≥ 4 ft and side slopes > 4:1
Ponding Depth	Minimum permanent pool depth required to sustain wet pool No limits on temporary ponding depth above wet pool

Design Element	
Freeboard	Minimum 1 foot above 10-year, 24-hour water surface elevation or as required by MDE dam safety criteria
Pond Layout	Maximize flow path from inflow points to outlet Recommend length to width ratio (L:W) of 1.5:1
Low Flow Orifice	Minimum opening diameter 3 inches or 1 inch if used as internal orifice with external anticlogging design
Vegetation	Follow landscaping guidance in Appendix H

Table 3.20 Summary of Design Elements for Dry Ponds
(with Extended Detention and/or Detention)

Design Element	
Application	Used to treat runoff for full or partial Cp_v where required Cp_v for discharge point is > 8,000 ft^3 Used to manage q_p and q_f for new development Used to manage q_p and q_f for redevelopment (if required)
Drainage Area	No limits
Conveyance	On-line or off-line as needed for design Safely pass the 10-year, 24-hour storm or as required by MDE dam safety criteria
Pre-treatment	Forebay required at every inlet that contributes 10% or more of total design storm inflow to pond Minimum forebay volume ≥ 0.1 inch per acre of impervious drainage area.
Soil type	All soil types
Groundwater	Design considerations but no limits
Soils Investigation	USDA Soil Survey and one test pit or boring in pond area indicating groundwater elevation or as required by MDE dam safety criteria
Storage Volume	Extended detention volume equal to 62% or 56% Cp_v runoff treatment volume depending on Use Class of watershed Minimum extended detention volume of 8,000 ft^3 Routing of detention volume for q_p and q_f may include extended detention volume
Side slopes and Benching	Internal and external embankment side slopes no steeper than 3:1 (H:V) or as required by MDE dam safety criteria Not applicable to underground detention/extended detention structures
Ponding Depth	No limits
Freeboard	For surface ponds, minimum 1 foot above 10-year, 24-hour water surface elevation or as required by MDE dam safety criteria For underground detention/extended detention structures, minimum 20% of design storm depth
Pond Layout	Standalone structure or part of another BMP Aboveground and underground allowed

Design Element	
Low Flow Orifice	Minimum opening diameter 3 inches or 1 inch if used as internal orifice with external anticlogging design
Vegetation	Follow landscaping guidance in Appendix H

Figure 3.15 Wet Extended Detention Pond

(Page intentionally left blank for future detail)

Figure 3.16 Wet Pond

(Page intentionally left blank for future detail)

Figure 3.17 Micro Topography for Multiple Cells

(Page intentionally left blank for future detail)

Figure 3.18 Dry Detention Pond

(Page intentionally left blank for future detail)

3.2.2 Stormwater Wetlands

Stormwater wetlands are practices where shallow wetland areas are created to treat urban stormwater runoff. These practices often incorporate small permanent pools and/or extended detention storage to manage the required water quality treatment.

Design types include:

- Shallow wetland
- Shallow extended detention wetlands

Stormwater wetlands that incorporate additional storage above the permanent pool may provide management of the q_p and q_f volumes. Stormwater wetlands that incorporate additional extended detention storage above the permanent pool may also provide management of the Cp_v when the Cp_v runoff volume from the discharge point of the development site is greater than 8,000 ft^3.

Function and Configuration:

Stormwater wetlands are a type of stormwater pond that maintains a permanent pool at an elevation needed to sustain living wetland plants over the pond bottom. The permanent pool and the wetland plants are used to provide water quality treatment for stormwater runoff draining to the practice. To be considered a stormwater BMP, the wetlands must be constructed for the purpose of managing stormwater runoff. Existing wetlands cannot be used or modified to provide stormwater management for new or redevelopment.

The stormwater pond performance criteria presented in Section 3.2.1 Stormwater Ponds and particularly those applicable to wet ponds also apply to the design and construction of stormwater wetlands. Additional criteria specific to stormwater wetland design are presented below.

Site Conditions

1. **Soils and Groundwater**
   - A water balance must be performed to demonstrate that a stormwater wetland can withstand a thirty-day drought at summer evaporation rates without completely drawing down.
   - Stormwater wetlands may not be located in areas of karst topography.
   - Stormwater wetlands may not be located within state or federal jurisdictional waters, including wetlands without obtaining appropriate state and federal wetlands and waterway permits.

2. **Setbacks and Clearances**
   - A wetland buffer should extend 25 feet outward from the maximum water surface elevation with an additional 15-foot setback to structures.

Design Criteria:

1. **Pretreatment:**
   - Sediment control is critical to sustaining stormwater wetlands. Consequently, forebays shall be provided and designed in the same manner as ponds (see Section 3.2.1).

2. **Layout, Dimensions, and Treatment Layers**
   - Micro-topography is encouraged to enhance wetland plant and aquatic habitat diversity.
   - For stormwater wetlands providing water quality treatment for redevelopment at least 25% of the total WQ_v shall be in deepwater zones with a minimum depth of four feet (the forebays and micropools may be used to meet this criteria). These criteria may be reduced if the wetland is located where thermal impacts are a primary concern (e.g., cold water resource area watersheds).
   - A minimum of 35% of the total surface area shall have a depth of six inches or less and at least 65% of the total surface area shall be shallower than 18 inches.

- Structures such as fascines or coconut rolls can be used to create shallow marsh cells in high energy areas of the stormwater wetland.
- A micropool is recommended at the control structure. A micropool is a three- to six-foot-deep pool used to protect the low flow pipe from clogging and prevent sediment resuspension.

Sizing Criteria:

1. The surface area of the entire stormwater wetland shall be at least 1.5% of the total drainage area to the facility.

Landscaping Plan:

1. A landscaping plan shall be provided that indicates the methods used to establish and maintain wetland coverage. Minimum elements of a plan include: delineation of pondscaping zones, selection of corresponding plant species, planting configuration, and sequence for preparing wetland bed (including soil amendments, if needed).

2. Landscaping plans for stormwater wetlands located within cold water resource area watersheds should incorporate features and plant species commonly found in wooded wetlands.

3. The landscaping plan should provide elements that promote greater wildlife and waterfowl use within the wetland and buffers.

4. Refer to Appendix H for landscaping criteria.

Table 3.21 Summary of Design Elements for Stormwater Wetland Ponds (with and without Extended Detention and Detention)

Design Element	
Application	Used to treat runoff for full or partial WQ_v for redevelopment Used to treat runoff for full or partial Cp_v where required Cp_v for discharge point is > 8,000 ft^3 Used to manage q_p and q_f for new development Used to manage q_p and q_f for redevelopment (if required)
Drainage Area	Minimum 10 acres
Conveyance	On-line or off-line as needed for design Safely pass the 10 year, 24-hour storm or as required by MDE dam safety criteria
Pre-treatment	Forebay required at every inlet that contributes 10% or more of total design storm inflow to pond Minimum forebay volume ≥ 0.1 inch per acre of impervious drainage area
Soil type	Not to be located in areas of karst topography
Groundwater	Water balance required to verify permanent pool will remain wet after 30-day drought conditions
Soils Investigation	USDA Soil Survey and one test pit or boring in pond area indicating groundwater elevation or as required by MDE dam safety criteria
Storage Volume	Deep water zones (depths ≥ 4 ft) ≥ 25% of WQ_v runoff treatment Wet pond without extended detention: • 100%WQ_v runoff treatment volume in wet pool Wet pond with extended detention: • 62% or 56% Cp_v runoff treatment volume as extended detention storage above wet pool • 50%WQv* as extended detention storage above wet pool • Minimum Cp_v runoff treatment volume of 8,000 ft^3 • 50%WQ_v* storage in wet pool *Refer to limitations in narrative Routing of detention volume for q_p and q_f may include extended detention volume
Side slopes and Benching	Internal and external embankment side slopes no steeper than 3:1 (H:V) or as required by MDE dam safety criteria Safety benching required where permanent pool ≥ 4 ft and side slopes > 4:1 Internal aquatic benching required

Design Element	
Ponding Depth	Minimum permanent pool depth required to sustain wet pool No limits on temporary ponding depth above wet pool
Freeboard	Minimum 1 foot above 10-year, 24-hour water surface elevation or as required by MDE dam safety criteria
Surface Area	Minimum 1.5% of contributing drainage area
Pond Layout	Maximize flow path from inflow points to outlet Recommend length to width ratio (L:W) of 1.5:1
Low Flow Orifice	Minimum opening diameter 3 inches or 1 inch if used as internal orifice with external anticlogging design
Vegetation	Follow landscaping guidance in Appendix H

Figure 3.19 Shallow Wetland

(Page intentionally left blank for future detail)

Figure 3.20 Extended Detention Shallow Wetland

(Page intentionally left blank for future detail)

3.2.3 Stormwater Infiltration

Stormwater infiltration practices capture and temporarily store stormwater runoff to promote infiltration into the soil over a prescribed period.

Design types include:

- Infiltration trench
- Infiltration basin

Infiltration practices can provide WQ_v, Re_v, and Cp_v but may only be used to meet WQ_v on redevelopment projects. Infiltration practices can also manage q_p and q_f through either infiltration or detention. Infiltration practices designed with extended detention storage for Cp_v and/or detention storage to manage q_p and/or q_f shall meet the requirements for dry ponds described in Section 3.2.1.

Function and Configuration:

The primary function of a stormwater infiltration practice is to provide groundwater recharge and water quality treatment. The effectiveness of both depends heavily on the in situ soil conditions and the ground water table elevation. Thus, detailed geotechnical analyses are required as part of the design.

The two basic types of stormwater infiltration practices are infiltration trenches and infiltration basins. An infiltration trench is linear practice with storage filled with gravel stone, and is suited for smaller drainage areas. The standard infiltration basin is an above-ground depression or excavated basin that captures and stores stormwater in an open area, allowing it to infiltrate into the ground. Infiltration practices can also be constructed below ground using underground chambers to provide storage above the infiltratable soils. Stormwater runoff is conveyed to a pretreatment area then to the surface of the infiltration practice where it is temporarily stored and then filtered through a sand or gravel media into the in situ soil.

Each type of infiltration practice provides the same functions for Re_v and each may provide WQ_v for redevelopment. Infiltration practices may be used to manage Cp_v only where the required Cp_v runoff volume for the discharge point from the development site is greater than 8,000 ft^3. Infiltration practices may be designed to manage Cp_v through infiltration into the ground or by providing extended detention storage volume above the WQ_v. Where Cp_v management is attained using infiltration processes, an infiltration practice may be used to manage a Cp_v runoff treatment volume less than 8,000 ft^3. However, due to practical orifice sizing limitations, an infiltration practice may not use extended detention to manage a Cp_v runoff treatment volume less than 8,000 ft^3. Infiltration basins can also be designed to meet q_p and/or q_f requirements through infiltration into the ground or by providing detention storage volume above the WQ_v and Cp_v.

Infiltration practices designed with extended detention storage for Cp_v and/or detention storage to manage qp and/or qf shall meet the design and construction standards for ponds, and in particular dry ponds, as described in Section 3.2.1 Stormwater Ponds.

Site Conditions

1. **Topography:**
   - Infiltration practices shall not be located on slopes greater than 15% or within fill soils

2. **Soils and Groundwater:**
   - Underlying soils shall have an infiltration rate of 0.52 inches per hour or greater, as initially determined from the USDA Soil Textural Triangle (See Appendix G) and subsequently confirmed by field geotechnical tests.
   - In situ soils shall have a clay content of less than 20% and a silt/clay content of less than 40%.

- The required geotechnical testing procedures for feasibility and design are outlined in Appendix A. The minimum required density of soil boring or test pits is one test hole per 5,000 ft^2, with a minimum of two borings per facility (taken within the proposed limits of the facility).
- Infiltration practices are prohibited within areas of karst topography. Recommended procedures for determining whether a site overlies karst are provided in Appendix B.
- The bottom of the infiltration practice shall be separated by at least 4 feet vertically from the seasonally high-water table or bedrock layer, as documented by the onsite geotechnical testing. This distance is reduced to 2 feet on the Eastern Shore (see Figure 4.1).

3. **Setbacks and Clearances:**
   - Infiltration practices shall be located a minimum of 100 feet horizontally from any water supply well.
   - Infiltration practices shall not be placed in locations that cause water problems to downgrade properties.
   - Infiltration practices shall be set back 25 feet down- gradient from any structure.

4. **Safety and Access:** Direct access shall be provided to all infiltration practices for maintenance and rehabilitation.

5. **Hotspot Runoff**:
   - To protect groundwater from possible contamination, runoff from designated hotspot land uses or activities shall not be treated using infiltration practices. A list of designated stormwater hotspots is provided in Chapter 4.

Design Criteria:

1. **Drainage Area and Size Limitation:** The maximum contributing area to an infiltration practice shall be less than 5 acres.

2. **Pretreatment:**
   - For practices treating the WQ_v, a minimum of 25% of the WQ_v runoff treatment volume must be pretreated prior to entry into an infiltration practice. If the soil infiltration rate for the underlying soils is greater than 2.0 inches per hour, 50% of the WQ_v runoff treatment volume shall be pretreated prior to entry into an infiltration practice.
   - Pretreatment exit velocities shall be non-erosive for the two-year design storm.
   - The Camp-Hazen equation (Section 3.2.4) may be used as an acceptable alternative for determining pretreatment requirements.

3. **Conveyance:**
   - A conveyance system into, through, and from all infiltration practices shall be included in the design to ensure that excess flow is discharged at non-erosive velocities.

- If runoff is delivered by a storm drain pipe or along the main conveyance system, runoff from storms greater than the design storm of the infiltration trench should be diverted around the practice.

4. **Layout, Dimensions, and Treatment Layers:**
   - The sides of infiltration trenches shall be lined with an acceptable filter fabric that prevents soil piping but has greater permeability than the parent soil (see Appendix I).
   - Infiltration practices should not be covered by an impermeable surface.
   - Each infiltration practice shall have redundant methods to protect the long-term integrity of the infiltration rate. At least three of the following techniques must be installed in every infiltration trench and two must be installed per basin:
     - grass filter strip (minimum 20 feet and only if sheetflow is established and maintained)
     - bottom sand layer
     - upper sand layer (6 inch minimum) with filter fabric at the sand/gravel interface.
     - use of washed bank run gravel as aggregate.

5. **Underdrains, Cleanouts, and Observation Wells**
   - An observation well, consisting of an anchored six-inch diameter PVC pipe with a lockable cap shall be installed in every infiltration trench. See Appendix D for specifications.
   - The top of the cleanout/observation well shall extend at least 6 inches above ground and shall be protected by a cage or constructed of material resistant to breakage from lawn mowers.
   - Infiltration practices shall include dewatering methods in the event of failure. This can be done with underdrain pipe systems that accommodate drawdown.

Sizing Criteria:

1. Infiltration practices shall be designed to infiltrate 100% of the design runoff treatment volume (i.e., Rev, WQ_v, or Cp_v) using the design methods outlined in Appendix G.

2. The truncated hydrograph method shall be used if infiltration (rather than extended detention or detention) is used to control Cp_v, q_p, or q_f.

3. A porosity value "n" ($n=V_v/V_t$) of 0.40 should be used in the design of stone reservoirs for infiltration trenches.

4. All infiltration practices designed to provide water quality treatment shall be designed to fully infiltrate the entire design volume within 48 hours.

Landscaping Plan:

1. The floor of an infiltration basin shall be stabilized with 100% coverage of herbaceous vegetation. See Appendix H.

Table 3.22 Summary of Design Elements for Infiltration Trench

Design Element	
Application	Used to treat runoff for full or partial WQ_v and Re_v for redevelopment Used to treat runoff for full or partial Cp_v where required Cp_v for discharge point from development site > 8,000 ft³
Drainage Area	Maximum contributing drainage area of 5 acres.
Conveyance	Runoff volumes larger than design runoff volume diverted around practice
Pre-treatment	Minimum 25% of WQ_v runoff treatment volume Minimum 50% of WQ_v runoff treatment volume where infiltration rate of underlying soils > 2 in/hr Use three of the following: • grass filter strip (minimum 20 feet and only if sheet flow is established and maintained) • bottom sand layer • upper sand layer (6 inch minimum) with filter fabric at the sand/gravel interface. • washed bank run gravel as aggregate
Soil type	Not allowed on fill Underlying insitu soils with infiltration rates ≥ 0.52 in/hr Insitu soils with clay content < 20% and a silt/clay content > 40% Prohibited in areas of karst topography
Groundwater	At least 4 ft below bottom of practice (2 ft for Eastern Shore)
Soils Investigation	One test pit or boring per 5,000 ft² of surface area and a minimum of two borings per practice
Storage Volume	Fully dewater the WQ_v within 48 hours 100% of the design runoff treatment volume (i.e., WQ_v or Cp_v) including forebay volume Volumes required for managing q_f and q_p
Side Slopes	Vertical side slopes for media storage below ground
Surface Area	Minimum calculated in accordance with Appendix X.
Freeboard	No ponding above trench

Design Element	
Filter Media	Gravel and pretreatment layers
Underdrain	None
Observation Wells	Minimum one per 2,000 ft^2
Vegetation	None

Table 3.23 Summary of Design Elements for Infiltration Basin

Design Element	
Application	Used to treat runoff for full or partial WQ_v and Re_v for redevelopment Used to treat runoff for full or partial Cp_v where required Cp_v for discharge point from development site > 8,000 ft^3 for new development and redevelopment (if required) Used to manage q_p and/or q_f through infiltration and/or in conjunction with detention
Drainage Area	Maximum contributing drainage area of 10 acres
Conveyance	Runoff volumes larger than design runoff volume diverted around practice Safely pass the 10-year, 24-hour storm or as required by MDE dam safety criteria
Pre-treatment	Minimum 25% of WQ_v runoff treatment volume Minimum 50% of WQ_v runoff treatment volume where infiltration rate of underlying soils > 2 in/hr Use two of the following for every infiltration trench: • grass filter strip (minimum 20 feet and only if sheet flow is established and maintained) • bottom sand layer • upper sand layer (6 inch minimum) with filter fabric at the sand/gravel interface. • washed bank run gravel as aggregate
Soil type	Not allowed on fill Underlying insitu soils with infiltration rates ≥ 0.52 in/hr Insitu soils with clay content < 20% and a silt/clay content > 40% Prohibited in areas of karst topography
Groundwater	At least 4 ft below bottom of practice (2 ft for Eastern Shore)
Soils Investigation	One test pit or boring per 5,000 ft^2 of surface area and a minimum of two borings per practice
Storage Volume	Fully dewater the WQ_v within 48 hours 100% of the design runoff treatment volume (i.e., WQ_v or Cp_v) including forebay volume Volumes required for managing q_f and q_p
Side Slopes	For surface structures, internal and external embankment side slopes no steeper than 3:1 (H:V) or as required by MDE dam safety criteria

Design Element	
Surface Area	Minimum calculated in accordance with Appendix X
Freeboard	For surface structures, minimum 1 foot above 10-year, 24-hour water surface elevation or as required by MDE dam safety criteria For underground structures, minimum 20% of design storm depth
Filter Media	None
Underdrain	None
Observation Wells	None
Vegetation	100% herbaceous vegetative cover for basins

Figure 3.21 Infiltration Tench

(Page intentionally left blank for future detail)

Figure 3.22 Infiltration Basin

(Page intentionally left blank for future detail)

3.2.4 Stormwater Filtering Practices

Stormwater filtering practices are designed to capture and temporarily store stormwater runoff and pass it through a filter bed of sand, organic matter, soil, or other media. Filtered runoff is collected, treated, and either returned to the conveyance system or infiltrated into the soil.

Stormwater filtering practices may be used to provide WQ_v treatment for redevelopment through the filter media. They may also be used to manage the Re_v if designed to infiltrate runoff into the soil (e.g., storage is provided below the outlet). Stormwater filtering practices may be used to provide Cp_v management only where the required Cp_v runoff volume for the discharge point from the development site is greater than 8,000 ft3. Cp_v management is provided through the filter media or by extended detention above the filter. A stormwater filtering practice may be combined with a pond or separate structure to meet q_p or q_f requirements. The filter shall not be used for q_p and q_f management.

Where filtering practice is combined with a separate compartment, cell, or forebay to provide detention storage to manage qp and/or qf, the structure shall be designed to meet the standards for ponds as described in Section 3.2.1 Stormwater Ponds.

Design types include:

- Sand Filter
  - Surface Sand Filter
  - Underground Sand Filter
  - Perimeter Sand Filter
- Bioretention
- Submerged Gravel Wetland
- Rainwater Harvesting

3.2.4.1 Sand Filters

Stormwater sand filters capture, temporarily store, and treat stormwater runoff by passing it through a filter bed of engineered sand media, collecting the filtered water in an underdrain, and then returning it back to the conveyance system.

Sand filters are versatile BMPs that occupy relatively little land surface and have few site restrictions. Sand filters can be applied to most urban settings, but there are situations where they are clearly the best option (e.g., hotspot runoff treatment and ultra-urban areas where space is at a premium).

There are several design variants of the basic sand filter which allows them to be adapted to challenging sites or situations where enhanced pollutant removal rates are necessary. The most common design variants and the ones included in this manual are surface, underground, and perimeter sand filters.

Where a sand filter is combined with a separate compartment, cell, or forebay to provide detention storage to manage qp and/or qf, the structure shall be designed to meet the standards for ponds, and in particular dry ponds, as described in Section 3.2.1 Stormwater Ponds.

Function and Configuration:

Sand filters can be used to provide WQ_v treatment for redevelopment. For surface sand filters, when a storage reservoir is provided below the underdrain, the practice may be used to provide Re_v. A surface sand filter without an underdrain must be capable of providing Re_v through infiltration of the in situ soil without needing additional storage. Sand filters contained within a concrete chamber (or other material) shall not be used to provide Rev.

Stormwater filtering practices may be used to provide Cp_v management through the filter media or by extended detention above the filter. However, Cp_v runoff treatment volumes less than 8,000 ft^3 may be managed only through the filter and not through extended detention above the filter due to practical orifice sizing limitations. Sand filters shall not be designed to manage q_p, or q_f.

Site Conditions:

1. **Topography**:
   - It is difficult to employ sand filters in extremely flat terrain, since they require gravity flow through the filter. An exception is the perimeter sand filter, which can be applied with as little as 2 feet of elevation change between the design surface storage elevation and the outlet invert.
   - If slopes entering these practices are too steep, then level-spreading devices such as check dams, terraces, or berms may be needed to maintain sheetflow.

2. **Soils and Groundwater:**
    - When designed with an underdrain collection system, a sand filter may be located in all HSG soils.
    - A surface sand filter may be designed without an underdrain where infiltration rates are greater than 0.52 in/hr and the bottom of the filter is at least 4 feet above the seasonally high-water table (2 foot on Eastern Shore).
    - When designed with an underdrain, the bottom of a surface sand filter (i.e., bottom of gravel layer) shall be located at least 2 feet above the seasonally high-water table (1 foot on Eastern Shore) or a liner shall be provided.
    - When underground sand filters are located in high groundwater, the design shall consider uplift forces and flotation.
    - Soils investigations shall include at least one test pit or boring per BMP and shall be conducted in accordance with Appendix A.

3. **Setbacks and Clearances:**
    - Surface sand filters should be located down gradient from structures and setback at least 10 feet. Underground sand filters that must be located adjacent to structures should include an impermeable liner.
    - Surface sand filters shall be located at least 30 feet from water supply wells and 25 feet from septic systems. If designed to provide recharge, then the practice shall be located at least 50 feet from confined water supply wells and 100 feet from unconfined water supply wells.
    - Sand filters shall be sized and located to meet minimum local requirements for clearance from underground utilities.

4. **Safety and Access:** For all underground sand filters, manholes or inlets with secured and accessible man hole steps shall be provided to the pretreatment area, the filter area, and the overflow chamber. Manholes and inlets shall be in compliance with standard specifications for each county with a minimum opening diameter of 30" to comply with OSHA confined space requirements. Manholes and inlets shall be covered with either a steel manhole cover, a grate cover, or an aluminum and steel louvered door. Steps shall be ten inches wide (minimum) and spaced at 12 inches on center. Steps shall be cast in place or drilled and mortared into the wall.

5. **Hotspot Runoff:** Sand filters with no potential for groundwater recharge may be used to treat runoff from hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are typically found in stormwater runoff.

Design Criteria

1. **Drainage Area and Size Limitation:**
   - o Sand filters are best applied on small sites where the contributing drainage area is as close to 100 percent impervious as possible to reduce the risk that eroded sediment will clog the filter.

2. **Pretreatment:**
   - o Where runoff volume greater than 2,000 ft^3 enters a sand filter as concentrated flow from a pipe or channel, a pretreatment forebay shall be provided. Refer to sizing criteria.
   - o Surface sand filters shall be sized with a stone "window" at the entrance of the inflow to promote filtration. The surface area of the stone window shall be equal to 10% of the sand filter bed. This stone window shall be filled with pea gravel.
   - o To prevent short circuiting, the underdrain gravel must be located at a minimum distance of 4 ft from the edge of the stone window.

3. **Conveyance:**
   - o Runoff shall enter, flow through, and exit the sand filter in a safe and non-erosive manner.
   - o Inflow to the pretreatment structure may be conveyed via sheetflow or concentrated flow, including but not limited to, depressed curbs with wheel stops, curb cuts, downspouts, storm drains, and catch basins. Concentrated points of inflow shall be protected with energy dissipation.
   - o Flow from the sand filter shall be discharged to a stable outfall designed for non-erosive velocities.
   - o Sand filters shall be designed off-line from the primary conveyance system. A flow splitter or other mechanism shall be provided to direct the WQ_v to the filtering practice and divert storms larger than this design storm around the practice to a stable, downstream conveyance system designed for non-erosive velocities for the 10-year storm. See Appendix E for critical non-erosive velocities for grass and soil.

4. **Layout, Dimensions, and Treatment Layers:**
   - o **Chambers:** All sand filters consist of two chambers: the first is for pretreatment or settling, and the second serves as a filter bed consisting of sand or other engineered filter media. An underdrain located in a gravel layer below the sand filter bed conveys the discharge from the filter. Underground sand filters have an additional third chamber that acts as an overflow and conveys discharge through an outlet pipe.
   - o **Surface storage:** The depth of the surface storage required to meet the head requirement ranges from 2 to 10 feet depending on the design. The ponding depth is measured from the top of the sand layer.
   - o **Sand Layer:** A minimum sand layer of 12 inches shall be provided - 18 inches or deeper is preferred. A deeper sand layer facilitates maintenance since sand can be removed without having to be replaced each maintenance cycle so long as the design depth is maintained.

- **Bridging Layer:** A bridging layer of a minimum of 3 inches of pea gravel shall be placed between the sand layer and the underdrain gravel.
- **Underdrain Gravel Layer:** The underdrain gravel layer shall be at least 12 inches deep including a minimum of 3 inches of gravel above the underdrain pipe and a minimum of 3 inches below the pipe.
- **Recharge Reservoir:** The Rev requirement may be met by providing a gravel reservoir below the underdrain. The recharge reservoir is a gravel sump located below the invert of the underdrain that provides storage for water to exfiltrate into the underlying soils without impeding drainage from the upper layers. The recharge reservoir should extend under the entire bottom of the filter area. Sand filters with impermeable liners or a concrete bottom do not provide recharge.
- **Geotextile:** Except when specifically noted in this Manual, geotextile shall not be provided along the top, bottom, or between any horizontal layer. The use of geotextile along the sides is optional.
- **Surface Sand Filter:**
    - The surface sand filter is designed with both the filter bed and pretreatment chamber or forebay located at ground level. The chambers can be constructed with earthen berms or within a concrete structure. The filter bed should be constructed without a slope.
    - Covering the surface of the sand filter bed protects it from the accumulation of trash, leaves, and debris as well as prevents biofouling or blinding of the sand surface. Surface sand filters can be protected with grass planted in a 3-inch layer of topsoil laid on top of a non-clogging geotextile directly above the sand layer.
    - Earthen side slopes of the ponding area in a surface sand filter shall be 3:1 (H:V) or flatter and should be vegetated with turf grass.
    - At least 12 inches of freeboard shall be provided above the 10-year water surface elevation. Additional freeboard may be required in accordance with MDE dam safety criteria.
    - If the underlying soils are infiltratable and there is an adequate clearance to groundwater, a surface sand filter can be designed without an underdrain.
- **Underground Sand Filter:**
    - Underground sand filters can be protected by permeable filter fabric, with a high flow through rate, covered with a thin layer of pea gravel; or, a wide mesh geotextile screen placed on the surface of the filter bed. The screen can be rolled up, removed, cleaned, and re-installed during maintenance operations.
    - Underground sand filters should be constructed with drain pipe and gate valve located within the overflow chamber just above the top of the filter bed to allow for dewatering if clogging occurs. The gate valve shall be accessible from the top of the chamber near the opening for maintenance. The gate valve stem shall be bolted to the chamber side wall.
    - A 5-foot minimum height clearance (from the top of the sand layer to the bottom of the upper/surface slab) is required for all permanent underground structures. Lift rings are to be supplied to remove/replace top slabs on prefabricated structures.

- Underground sand filters with a total internal volume greater than 1.5 acre-feet shall be submitted to the MDE for screening and may possibly require a dam safety permit.

5. **Underdrains, Cleanouts, and Observation Wells:**
   - o The underdrain shall be sized so that the surface storage volume and media storage volume fully drain within 40 hours.
   - o The diameter of underdrain shall be at least 4 inches.
   - o The underdrain shall not be wrapped in geotextile.
   - o Multiple underdrains may be necessary for filter areas wider than 40 feet. Each underdrain should be located no more than 20 feet from the next pipe or the edge of the filter area.
   - o The preferred slope of the underdrain is 0.5%
   - o The underdrain shall not be wrapped in geotextile.
   - o A cleanout pipe shall be located at the upgrade end of each underdrain run and also at every bend (i.e., T's and Y's). The length of pipe between cleanouts shall be no greater than 150 ft.
   - o A minimum of one observation well must be provided for every 2,000 ft2 of filter area.
   - o The observation well and cleanout can be combined.
   - o The top of the cleanout/observation shall extend at least 6 inches above ground and shall be protected by a cage or constructed of material resistant to breakage from lawn mowers.
   - o Underdrains, cleanouts, and observation wells shall conform to the piping specifications found in Appendix I.

Sizing Criteria

1. **Pretreatment**
   - o Dry or wet pretreatment of a volume equivalent to at least 25% of the WQ_v shall be provided prior to runoff entering the filter area. The typical pretreatment method is to use a sediment forebay that has a length to width ratio of 2:1.

2. **Sizing Criteria**
   - o The entire treatment system (including pretreatment) shall temporarily hold at least 75% of the WQ_v or Cp_v runoff treatment volume in a surface storage area prior to flow through the filtering media. The height of the surface storage area shall be measured from the top of the sand layer.
   - o The required surface area of the sand filter shall be sized based on the principles of Darcy's Law and computed using the following equation:

$$Af = (\mathrm{V} \times df) \,/\, (k \times (hf + df) \times tf) \qquad \text{(Equation 3.2)}$$

where:

A_f = required surface area of filtering media (ft^2)
V = 100% of WQ_v or Cp_v runoff treatment volume (ft^3)
d_f = filtering media depth (ft)

k = coefficient of permeability of sand = 3.5 ft/day (City of Austin 1988)
h_f = average height of surface storage above filtering media (ft)
t_f = filtering media drain time = 1.67 days

- Where a sand filter is used to manage Cp_v a low flow control orifice shall be provided at the downstream end of the underdrain in an accessible location and configured in a way that will prevent clogging.
- Surface sand filters covered with grass shall require adjustments to Equation 3.2 in accordance with Appendix J.
  The provided Re_v is calculated from the volume of the recharge reservoir and shall be equal to the volume below the invert out of the underdrain, multiplied by a porosity of 0.4.
- The provided Rev cannot be larger than the runoff to the BMP for the water quality design storm (i.e., WQ_v to the BMP).
- Because the WQ_v is based on surface storage and filter area, and the recharge reservoir is located after the filtration process, the Rev is not included in the provided WQ_v calculations.

Landscape Plan

1. Surface sand filters may have a grass cover to aid in pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought (see Appendix H for grass species selection guide).

Table 3.24 Summary of Design Elements for Sand Filters

Design Element	
Application	Used to treat runoff for full or partial WQ_v for redevelopment Used to treat runoff for full or partial Re_v Used with new development to manage Cp_v where Cp_v requirement to discharge point from development site > 8,000 ft^3
Drainage Area	Drainage area includes footprint surface sand filter practice
On-line/Off-line	Design off-line from primary conveyance system
Pre-treatment	When concentrated runoff volume > 2,000 ft^3, a pre-treatment forebay is required Provide stone window equal to 10% of filter bed for surface sand filters Pretreatment volume to be at least 25% of WQ_v
Soil type	For surface sand filters: all HSG soils if designed with underdrain; without an underdrain: infiltration rate > 0.52 in/hr
Groundwater	For surface sand filters: without an underdrain, ≥4 feet below bottom of gravel layer (2 ft for Eastern Shore with an underdrain, ≥ 2 feet below bottom of gravel layer (1 ft for Eastern Shore) or provide a liner
Soils Investigation	One test pit or boring per BMP
Storage Volume	75% of design runoff treatment volume (i.e., WQ_v or Cp_v)
Side slopes	For surface sand filters: No steeper than 3:1 (H:V) Turf grass cover preferred on slopes
Surface Ponding Depth	Minimum 2 feet Maximum 10 feet
Freeboard	Minimum 12 inches above 10-year WSEL or as required in accordance with MDE dam safety criteria
Surface Area	Min A_f = (design runoff volume)(d_f)/[(k)(h_f + d_f)(t_f)] Where: A_f = surface area of bio-filter (ft^2) Design runoff volume = WQ_v or Cp_v(ft^3) d_f = bio-filter bed depth to invert of underdrain (ft) k = coefficient of permeability of sand = 3.5 ft/day h_f = average height of water above filter bed (ft) t_f = design filter bed drain time (days)
Recharge Sump	For surface sand filters: gravel reservoir below underdrain ≥ required for Rev Porosity of gravel media = 0.4

Design Element	
Filter Media	Typically, 18 inches of sand and no less than 12 inches. Bridging layer of minimum 3 inches of sand and minimum 3 inches of pea gravel Minimum 10 inches of gravel (minimum 3 inches above and below underdrain)
Underdrain	Minimum 4-inch diameter perforated or slotted pipe Sized to drain surface and media storage volume in 40 hours Maximum 20 ft spacing from pipe to pipe Preferred slope 0.5%
Observation Wells	Minimum one per 2,000 ft^2 of filter area
Cleanouts	Provide at end of underdrain runs and at T's and Y's Maximum 150 ft pipe length between cleanouts
Vegetation	Follow landscaping guidance in Appendix H

Figure 3.23 Surface Sand Filter

(Page intentionally left blank for future detail)

Figure 3.24 Perimeter Sand Filter

(Page intentionally left blank for future detail)

Figure 3.25 Underground Sand Filter

(Page intentionally left blank for future detail)

3.2.4.2 Bioretention

Bioretention practices are volume-based structures that retain and treat stormwater runoff through settling, filtration, and biological and chemical transformation. Stormwater runoff is temporarily stored on the surface of the practice, filtered through a mulch layer and an underlying bioretention soil media layer composed of a mixture of sand, soil, and organic matter. Stormwater runoff then flows through a sand and pea gravel bridging layer followed by a second gravel layer that holds an underdrain. Filtered stormwater discharges through the underdrain. When additional storage is provided in excess gravel below the underdrain, bioretention also provides groundwater recharge.

Bioretention is a larger structural version of the micro-bioretention practice. The principles and criteria for designing micro-bioretention and bioretention are basically identical with the only tangible difference being the size of the practice. While micro-bioretention is an ESD practice that can provide water quality treatment for new development, the larger bioretention variation can provide water quality treatment only for redevelopment. Bioretention may also be used to provide Re_v, Cp_v, and q_p and q_f. Bioretention practices may be used to manage Cp_v only where the required Cp_v for the discharge point from the development site is greater than 8,000 ft^3. Due to practical orifice sizing limitations, a bioretention practice may not be used to manage a Cp_v runoff treatment volume less than 8,000 ft^3.

Function and Configuration:

The function and configuration of bioretention practices is similar to that of micro-bioretention practices. Refer to Section 3.1.3.4 for additional information on function and configuration of bioretention practices.

Site Conditions: The design of bioretention facilities shall follow all of the site conditions criteria listed in Section 3.1.3.4 as well as meet the additional criteria listed below:
.
1. **Soils and Groundwater:** Soils investigations shall include at least one test pit or boring per facility and shall be conducted in accordance with Appendix A.

2. **Safety and Access:** Direct maintenance access shall be provided to the pretreatment area and the filter area.

Design Criteria: The design of bioretention facilities shall follow all of the design criteria listed in Section 3.1.3.4 as well as meet the additional criteria listed below:

1. **Pretreatment:** Adequate pretreatment for sheetflow shall be provided in the form of a stone diaphragm along the perimeter of the practice. The stone diaphragm shall be at least six inches deep.

2. **Layout, Dimensions, and Treatment Layers:**

- o The bioretention filter shall not be used to manage the q_p or q_f. No routing of these volumes or design storms shall be allowed through the bioretention filter.
- o q_p, or q_f volumes shall be located above the surface storage volume required for WQ_v and/or Cp_v.
- o Where bioretention is used to manage Cp_v a low flow control orifice shall be provided at the downstream end of the underdrain in an accessible location and configured in a way that will prevent clogging.
- o The minimum allowable orifice diameter for the low flow control is 1 inch (i.e., A=0.785 in2). If the computed orifice area is less than 0.785 in2, use a 1-inch orifice.
- o At least 12 inches of freeboard shall be provided above the 10-year, 24-hour design water surface elevation. Additional freeboard may be required in accordance with MDE dam safety criteria.
- o All joints and pipe openings through the walls of the control structure shall be completely watertight including underdrain piping

3. **Underdrains, Cleanouts, and Observation Wells:** The minimum diameter of the underdrain pipe shall be 6 inches. The underdrain shall not be wrapped in geotextile.

Sizing Criteria: The design of bioretention facilities shall follow all of the sizing criteria listed in Section 3.1.3.4 as well as meet the additional criteria listed below:

1. The required surface area of the bioretention filter shall be sized based on the principles of Darcy's Law and computed using the following equation:

$$Af = (WQv\ or\ Cpv)\ \times df)\ /\ (k\ \times (\ hf + df) \qquad \text{(Equation 3.3)}$$

where:

A_f	= required surface area of filtering media (ft^2)
WQ_v or Cp_v	= water quality volume (ft^3) or channel protection volume (ft^3) depending on purpose of BMP
d_f	= filtering media depth (ft)
k	= coefficient of permeability of bioretention soil media = 1.0 ft/day (Virginia, 2024)
h_f	= average height of water above filtering media (ft)
t_f	= filtering media drain time = 2 days

Table 3.25 Summary of Design Elements for Bioretention Facilities

Design Element	
Application	Used with redevelopment to treat runoff for full or partial WQ_v and Re_v Used with new development to manage Cp_v where Cp_v requirement to discharge point from development site > 8,000 ft^3 Used with new development and redevelopment to provide qp and qf management. q_p and q_f management must be provided above the WQ_v /Cp_v surface storage elevation. No routing of q_p or q_f through the filter bed
On-line/Off-line	Practice must be off-line unless managing Cp_v, q_p, or q_f
Pre-treatment	Stone diaphragm is required to surround the perimeter of the practice
Soil type	HSG C/D HSG A/B when infiltration rates are unacceptable for infiltration or location requires an underdrain
Groundwater	At least 2 ft below bottom of gravel layer (1 ft for Eastern Shore)
Soils Investigation	One test pit or boring per facility
Storage Volume	75% of the design runoff treatment volume for WQ_v and/or Cp_v
Side slopes	No steeper than 3:1 (H:V) Turf grass cover preferred on slopes
Ponding Depth	Minimum 3 inches Maximum 12 inches for WQ_v and Cp_v
Freeboard	Minimum 12 inches above 10-year WSEL or as required in accordance with MDE dam safety criteria
Surface Area	Min A_f = (design runoff volume)(d_f)/[(k)(h_f + d_f)(t_f)] Where: A_f = surface area of bio-filter (ft^2) Design runoff volume = WQ_v or Cp_v(ft^3) d_f = bio-filter bed depth to invert of underdrain (ft) k = coefficient of permeability of bioretention soil media = 1.0 ft/day h_f = average height of water above filter bed (ft) t_f = design filter bed drain time (days)
Recharge Sump	Gravel reservoir below underdrain ≥ required Re_v Porosity of gravel media = 0.4
Filter Media	Minimum 24 inches of bioretention soil media Bridging layer of minimum 3 inches of sand and minimum 3 inches of pea gravel Minimum 10 inches of gravel (minimum 3 inches above and below underdrain)

Underdrain	Minimum 6-inch diameter perforated or slotted pipe Maximum 20 ft spacing from pipe to pipe Preferred slope 0.5%
Low Flow Orifice	Release time = 36 hours (18 hours for Use III/IV coldwater) Minimum 1 inch orifice diameter
Observation Wells	Minimum one well per 2,000 ft^2 of filter area
Cleanouts	Provide at end of underdrain runs and at T's and Y's Maximum 150 ft pipe length between cleanouts
Surface Cover	Minimum 3 inches of mulch Only use shredded hardwood mulch since other types float In special situations, coir or jute matting, river stone, or pea gravel may be used
Vegetation	Follow landscaping guidance in Appendix H

Figure 3.26 Bioretention

(Page intentionally left blank for future detail)

3.2.4.3 Submerged Gravel Wetland

A submerged gravel wetland is a volume-based flow through treatment system with wetland plants rooted in a rock or gravel media. Runoff is temporarily retained on the surface above the wetland soil and then filtered through a saturated ("submerged") gravel substrate before discharging.

Submerged gravel wetlands treat stormwater runoff through attenuation, settling, filtration, physical and chemical adsorption, microbial transformation, and uptake. Settling of particulate matter occurs in the pretreatment forebay and above the wetland surface. Filtering and adsorption occur as stormwater runoff passes through the system. Biological uptake from algae and bacteria microbes growing within the gravel substrate removes additional pollutants

The conversion and removal of nitrogen is dependent on aerobic conditions in the settling forebay and anerobic conditions in a subsurface treatment cell(s). Aerobic conditions are maintained when the forebay fluctuates between dry conditions and temporary ponding. Anaerobic conditions are maintained in the treatment cell(s) with saturated conditions from the high water table and slow flow through the gravel layer. This lowers the dissolved oxygen level to allow nitrate conversion to nitrogen gas.

A submerged gravel wetland is a larger structural version of the smaller pocket submerged gravel wetland presented in Section 3.1.3.7. The principles and criteria for designing a submerged gravel wetland and a pocket submerged gravel wetland are identical with the only tangible difference being the size of the practice. While the pocket submerged gravel wetland is an ESD practice that can provide water quality treatment for new development, the larger submerged gravel wetland may be used to provide water quality treatment only for redevelopment. Submerged gravel wetlands may also be used to provide Re_v, Cp_v, q_p and q_f. Submerged gravel wetlands may be used to manage Cp_v only where the required Cp_v runoff volume for the discharge point from the development site is greater than 8,000 ft^3. Due to practical orifice sizing limitations, a submerged gravel wetland may not be used to manage a Cp_v runoff treatment volume less than 8,000 ft^3.

Function and Configuration:

The function and configuration of a submerged gravel wetland is similar to that of a pocket submerged gravel wetland. Refer to Section 3.1.3.7 for additional information on function and configuration of submerged gravel wetlands.

Site Conditions: The design of submerged gravel wetlands shall follow the criteria listed in Section 3.1.3.7 Pocket Submerged Gravel Wetland as well as meet the additional criteria listed below:

1. **Soils and Groundwater:** Soils investigations shall include at least one test pit or boring per facility and shall be conducted in accordance with Appendix A.

2. **Safety and Access:** Direct maintenance access shall be provided to the pretreatment area and the filter area.

Design Criteria: The design of submerged gravel wetlands shall follow the design criteria listed in Section 3.1.3.7 as well as meet the additional criteria listed below:

1. **Pretreatment:** Adequate pretreatment for sheetflow shall be provided in the form of a stone diaphragm along the perimeter of the practice. The stone diaphragm shall be at least six inches deep.

2. **Layout, Dimensions, and Treatment Layers:**
   - More than one wetland treatment cell may be required for a submerged gravel wetland with multiple inflow locations, large drainage areas, or oddly configured sites.
   - The wetland treatment cells shall not be used to manage the q_p or q_f. No routing of these volumes or design storms shall be allowed through the treatment cells.
   - q_p or q_f storage shall be located above the surface storage required for WQ_v and or Cp_v.
   - Where a submerged gravel wetland is used to manage Cp_v a low flow control orifice shall be provided at the downstream end of the underdrain in an accessible location and configured in a way that will prevent clogging.
   - The minimum allowable orifice diameter for the low flow control is 1 inch (i.e., A=0.785 in^2). If the computed orifice area is less than 0.785 in^2, manage Cp_v in a practice that does not rely on an orifice for slow release (e.g., micro-bioretention, bioretention, infiltration, sand filter).
   - At least 12 inches of freeboard shall be provided above the 10-year, 24-hour design water surface elevation. Additional freeboard may be required in accordance with MDE dam safety criteria.
   - All joints and pipe openings through the walls of the control structure shall be completely watertight including underdrain piping

3. **Underdrains, Cleanouts, and Observation Wells:** The minimum diameter of the underdrain pipe shall be 6 inches. The underdrain shall not be wrapped in geotextile.

Sizing Criteria: The design of submerged gravel wetlands shall follow the criteria listed in Section as well as meet the additional sizing criteria listed below:

1. The low flow control orifice shall be provided to slowly release the WQ_v over 36 hours (or 18 hours for Use Class III/IV watersheds). The long residence time enhances the pollutant removal process. Hydraulic control of the system shall be set at 4 inches below the top of the wetland soil. The control orifice shall be provided at the downstream end of the underdrain in an accessible location and configured in a way that will prevent clogging. The required orifice area shall be calculated according to the method in Appendix J.

Table 3.26 Summary of Design Elements for Submerged Gravel Wetland

Design Element	
Application	Used for redevelopment to treat full or partial runoff for WQ_v Used for Re_v unless there is a liner Used for new development and redevelopment to treat runoff for Cp_v Used for new development and redevelopment to provide q_p and q_f Storage for managing q_p and q_f provided above the WQ_v or Cp_v Routing of q_p and q_f through the filter bed is not allowed
On-line/Off-line	Runoff volumes larger than design runoff volume diverted around practice
Pre-treatment	When concentrated runoff volume > 2,000 ft^3, a pre-treatment forebay is required
Soil type	HSG C or D soils with high ground water table
Soils Investigation	One test pit or boring per 1 acre of site disturbance indicating groundwater elevation
Storage Volume	Surface Storage: 100% of the design runoff treatment volume (i.e., WQ_v or Cp_v) Media Storage: 100% of the design runoff treatment volume (i.e., WQ_v or Cp_v)
Side slopes	No steeper than 3:1 (H:V) Dense vegetative cover required on slopes
Ponding Depth	Minimum 6 inches Maximum 24 inches for WQ_v or Cp_v
Freeboard	Minimum 12 inches above 10-year WSEL or as required in accordance with MDE dam safety criteria
Filter Media	Minimum 8 inches of wetland soil Minimum 3 inches of pea gravel as bridging layer Gravel layer ≥ 18 inches and ≤ 48 inches deep
Underdrain	Collection pipe with minimum 4-inch diameter with minimum 3 inches gravel below invert
Outlet	Outlet pipe (e.g., J-hook) set 4 inches below top of wetland soil and at least 6 inches above the seasonally high groundwater table
Observation Wells	Minimum one per 2,000 ft^2 of media area
Cleanouts	Provide at end of underdrain runs and at T's and Y's Maximum 150 ft pipe length between cleanouts
Vegetation	Follow landscaping guidance in Appendix H

Figure 3.27 Submerged Gravel Wetland

(Page intentionally left blank for future detail)

3.2.4.4 Rainwater Harvesting

Rainwater harvesting practices are volume-based practices that intercept and store rainfall for future use. Stored water may be used for non-potable water supply such as car washing or landscape irrigation. The capture and reuse of rainwater promotes conservation, as well as reduces runoff volumes and the discharge of pollutants downstream.

Function and Configuration:

Rainwater harvesting can be used to meet the water quality treatment and Cp_v requirements for new development and redevelopment. Larger storage tanks or cisterns are used in commercial or industrial applications. These systems use captured rainwater for non-potable water supply or large scale irrigation, usually providing a year-round source. Large scale reuse applications may require separate plumbing, pressure tanks, pumps, and backflow preventers. Seasonal demand variability and the need for alternative dewatering methods should be considered for commercial landscape irrigation reuse.

The pollutant removal capability of rainwater harvesting systems is directly proportional to the amount of runoff captured, stored, and reused. Therefore, the amount of runoff treated from the contributing drainage area is based on the volume captured and reused prior to the next rainfall. In addition, Re_v requirements are met only when stored water is used on landscaped areas to allow infiltration.

Site Conditions:

1. **Topography:** Locating storage tanks in low areas may increase the volume of rainwater stored but will require pumping for distribution.

2. **Setbacks and Clearances:** Space limitations can be overcome if storage is provided on the roof or underground. The proximity to building foundations also needs to be considered for dewatering and overflow conditions.

3. **Safety and Access:**
    - Access shall be provided for cleaning, inspection, and maintenance in all cisterns. A drain plug shall also be provided to allow the system to be completely emptied if needed. During the non-growing season, irrigation systems are typically turned off and may need to be dewatered.
    - Above ground storage tanks shall have secured openings small enough to prevent child entry. For underground systems, manholes shall be secured to prevent unauthorized access.
    - Rainwater storage designs need to consider the potential for freezing. These systems may need to be located indoors or underground below the frost line if freezing conditions are expected.

4. **Hotspot Runoff:** Rainwater harvesting systems shall not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than found in typical stormwater runoff and may contaminate groundwater.

Design Criteria:

1. **Drainage Area and Size Limitation:** The drainage area to each storage tank needs to consider year-round water demands.

2. **Pretreatment:** Screens or covers should be provided to prevent mosquitoes and other insects from entering the tanks.

3. **Conveyance:**
   - A stable discharge shall be provided for any dewatering.
   - Conveyance to rainwater harvesting storage tanks consists of gutters, downspouts, and pipes.
   - An overflow shall be provided to pass larger storm events. The overflow should be near the top of the storage unit and may consist of hosing or piping to direct runoff safely to a stable outfall.
   - Most outdoor distribution is gravity fed or can be operated with a pump. For underground tanks or cisterns, a pump, pressure tank, and backflow preventer will be needed.
   - Overflow devices shall be designed to avoid ponding or soil saturation within 10 ft. of building foundations.

4. **Layout, Dimensions, and Treatment Layers:** Large capacity systems shall provide dead storage below the outlet and an air gap at the top of the tank. Gravity-fed systems should provide a minimum of six inches of dead storage. For systems using a pump, the dead storage depth will be based on the pump specifications.

5. **Underdrains, Cleanouts, and Observation Wells:** An observation well consisting of an anchored pipe (4” min.) shall be provided on all below-ground installations. The top of the observation well shall be at least six inches above grade and shall be protected by a cage or constructed of material resistant to breakage from lawn mowers.

.

Sizing Criteria:

1. Cisterns shall be designed to capture the required rainfall depth for water quality treatment from the contributing rooftop area.
2. The design shall plan for dewatering to vegetated areas
3. Where rainwater harvesting systems are connected to indoor plumbing, the Rev requirement shall be addressed separately.
4. The design of large commercial and industrial storage systems shall be based on water supply and demand calculations. Stormwater management calculations shall include the discharge

rate for distribution and demonstrate that captured rainwater will be used prior to the next storm event.

Figure 3.28 Cistern

(Page intentionally left blank for future detail)