# APPENDIX E – DESIGN CRITERIA FOR POST-CONSTRUCTION WATER QUALITY BMPS

This Appendix presents design criteria for Post-Construction Water Quality BMPs to meet 80% TSS removal for use on SCDOT projects:

**Section E.1 Standard Application Permanent Structural Controls**

- Section E.1.1 Grassed Channels and Swales
- Section E.1.2 Vegetated Filter Strips
- Section E.1.3 Dissolved Oxygen Enhancement Structures
- Section E.1.4 Dry Detention Basins
- Section E.1.5 Wet Detention Basins
- Section E.1.6 Infiltration Trench

**Section E.2 Limited Application Structural BMPs**

- Section E.2.1 Bioretention Areas
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- Section E.2.3 Natural Infiltration
- Section E.2.4 Stormwater MTDs

## E.1 STANDARD APPLICATION PERMANENT STRUCTURAL CONTROLS

### E.1.1 Grassed Channels and Swales

#### E.1.1.1 Description

Vegetated channels, vegetated swales, and vegetated filter strips are the primary water quality BMPs utilized by SCDOT.

The standard application for water quality applies only to the last 100 feet of Grassed Channels and Swales prior to outfall and does not include the entire conveyance. Grassed Channels and Swales are designed and installed as a stormwater conveyance system. Grassed Channels and Swales improve water quality by providing pollutant removal as runoff is filtered by the vegetation and by the opportunity to infiltrate the runoff into the underlying soil layer. Grassed Channels and Swales also reduce flow velocities in comparison to hard piping systems.

**When and Where to Use**

Grassed Channels and Swales are commonly installed along roadway and sidewalk corridors. Grassed Channels and Swales require continual permanent vegetative cover in order to provide adequate treatment of runoff. It is important to maximize water contact with vegetation and the soil surface. Plant all Grassed Channels and Swales with permanent turf type grasses according to SCDOT Supplemental Technical Specification for Seeding SC-M-810-2 or latest revision.

Grassed Channels and Swales are susceptible to erosion and channelization if a thick stand of permanent vegetation is not sustained. A thick permanent vegetative cover is essential for proper functioning and to prevent damage from erosion.

**Application and Limitations**

The suitability of Grassed Channels and Swales depends on land use, size of the DOT right-of –way (ROW) drainage area, soil type, slope, imperviousness of the contributing watershed, and dimensions and slope of the channel system. Grassed Channels and Swales are not designed to treat DOT ROW drainage areas greater than five acres. Large drainage areas may be divided into sub-watersheds and treated using multiple Grassed Channels and Swales.

#### E.1.1.2 Design Requirements

To achieve 80% removal efficiency of the average annual post-development TSS load, Grassed Channels and Swales must have a minimum flow length of 100-feet with 0.5 ft. high earthen flow control structures installed according to Table E.1. If site constraints do not allow 100-feet, vegetated swales with a slope less than or equal to 1% and a DOT ROW drainage area less than or equal to 0.5 acres may be 75-feet long with a minimum of five 0.5 ft. high earthen flow control structures installed.

For maximum water quality performance where applicable, Grassed Channels and Swales are recommended to be off-line structures. If Grassed Channels and Swales are designed to be online structures, they must be able to safely convey the runoff of the 10-year, 24-hour storm event.

Design Grassed Channels and Swales with 1 foot of freeboard distance above the 10-year, 24-hour storm water surface elevation, if site conditions allow.

**Table E.1: Grassed Channels and Swales Earthen Flow Control Structures Requirements**

<table>
<tr><th rowspan="2">Maximum DOT ROW Drainage Area (acres)</th><th rowspan="2">Maximum Vegetated Channel Longitudinal Slope</th><th colspan="2">Number of Earthen Flow Control Structures Required</th></tr>
<tr><th>Upper State</th><th>Lower State</th></tr>
<tr><td rowspan="5">0.25</td><td>≤ 0.5%</td><td colspan="2" rowspan="2">3 per 100 ft</td></tr>
<tr><td>1.0%</td></tr>
<tr><td>2.0%</td><td rowspan="2">5 per 100 ft</td><td rowspan="3">5 per 100 ft</td></tr>
<tr><td>4.0%</td></tr>
<tr><td>6.0%</td><td>7 per 100 ft</td></tr>
<tr><td rowspan="4">0.50</td><td>≤ 0.5%</td><td colspan="2" rowspan="2">5 per 100 ft</td></tr>
<tr><td>1.0%</td></tr>
<tr><td>2.0%</td><td colspan="2" rowspan="2">6 per 100 ft</td></tr>
<tr><td>4.0%</td></tr>
<tr><td>1.00</td><td>≤ 0.5 – 4.0%</td><td colspan="2">6 per 100 ft</td></tr>
<tr><td>2.00</td><td>≤ 0.5 – 4.0%</td><td colspan="2">7 per 100 ft</td></tr>
<tr><td>3.00</td><td>≤ 0.5 – 4.0%</td><td colspan="2">8 per 100 ft</td></tr>
<tr><td>4.00</td><td>≤ 0.5 – 4.0%</td><td colspan="2">9 per 100 ft</td></tr>
<tr><td rowspan="2">5.00</td><td>≤ 0.5 – 1.0%</td><td rowspan="2">10 per 100 ft</td><td>9 per 100 ft</td></tr>
<tr><td>2.0 – 4.0%</td><td>10 per 100 ft</td></tr>
</table>

Perform the design of Grassed Channels and Swales for the following two design conditions:

**Stability/Permissible Velocity**: This design process involves evaluating how the Vegetated Swales will respond under low vegetation retardance conditions. This condition is defined when vegetation is cut low or lies down, producing a lower Manning's n value, lower flow depths, and higher flow velocities. The limiting factor for stability design is the permissible velocity of the flow in the Vegetated Swales.

**Capacity**: This design process involves evaluating how the Vegetated Swales will respond under high vegetation retardance conditions. This condition is defined when vegetation is not maintained or is very long and rigid, producing a higher Manning's n value, higher flow depths, lower flow velocities, and higher shear stresses. The limiting factor for capacity design is the cross sectional area of the Vegetated Swales and the design shear stress.

**Table E.2: Grassed Channel Maximum Permissible Velocities**

| **Permanent Cover** | **Max Permissible Velocity (ft/sec) Without TRM*** | | | | | |
|---|---|---|---|---|---|---|
| | **Erosion-Resistant (*Clay, Sandy Clay, Sandy Clay Loam, Clay Loam, Silty Clay, Silty Clay Loam*) Soils % Slope** | | | **Easily Eroded (*Sand, Loamy Sand, Sandy Loam, Loam, Silty Loam, Silt*) Soils % Slope** | | |
| | **0-5** | **5-10** | **> 10** | **0-5** | **5-10** | **> 10** |
| Common Bermuda grass | 8 | 7 | 6 | 6 | 5 | 4 |
| Bahia<br>Carpet grass<br>Centipede Grass<br>Tall Fescue | 7 | 6 | 5 | 5 | 4 | 3 |
| Grass-legume Mixture | 5 | 4 | NR | 4 | 3 | NR |

**Allow velocities over 5 ft/sec only where good cover and maintenance will be provided. If fair or poor vegetation is expected due to shade, climate, soils or other factors, reduce the permissible velocity.*

*NR = Not Recommended*

**Table E.3: Grassed Channel Maximum Shear Stress**

| **Permanent Cover Good Stand*** | **Typical Retardance Class**** | **Max Permissible Shear Stress ( # / $ft^2$) Without TRM***** |
|---|---|---|
| Common Bermuda grass (12-inch)<br>Tall Fescue (18-inch, unmowed) | B | 2.1 |
| Common Bermuda grass (6-inch)<br>Bahia (6 to 8 inch)<br>Centipede Grass (6 inch)<br>Tall Fescue (6 to 12 inch) | C | 1.0 |
| Grass-legume Mixture (4 to 5 inch) | D | 0.6 |
| Common Bermuda grass (1.5-inch, mowed) | E | 0.35 |

* *Values represent good cover and maintenance. If fair or poor vegetation is expected due to shade, climate, soils or other factors, reduce the permissible shear stress.*

** *Source: US. Soil Conservation Service (1969, 1986), Soil Conservation Service Field Manual (1979)*

****Source: FHWA/Chen and Cotton (1998)*

Consider the following hydraulic design requirements for all Grassed Channels and Swales installations:

- Where applicable, minimum channel slope of 0.5 percent. In all cases Grassed Channels and Swales should have enough slope to properly drain and convey runoff.
- Maximum channel slope of 6% for DOT ROW drainage area up to 0.25 acres. Maximum channel slope of 4% for DOT ROW drainage area up to 5 acres.
- Provide a 2-foot minimum bottom width, with a level bottom to the MEP. V-shaped ditches shall not be used.
- Non-erosive peak runoff velocities and shear stresses for 10-year, 24-hour storm event and capable of conveying the 10-year, 24-hour storm event without overtopping.
- The standard application for water quality applies only to the last 100 feet of Grassed Channels and Swales prior to outfall and does not include the entire conveyance.
- Minimum length of 100-feet with 0.5 ft. high earthen flow control structures installed according to Table E.1 to achieve water quality benefits. The maximum DOT ROW drainage area to grassed channels and swales is 5 acres. If site constraints do not allow 100-feet, Grassed Channels and Swales with a slope less than or equal to 1% and a DOT ROW drainage area less than or equal to 0.5 acres may be 75-feet long with a minimum of five 0.5 ft. high earthen flow control structures installed.
- Provide a Forebay and/or energy dissipation at all pipe inlets to Grassed Channels and Swales where applicable.
- Side slopes no steeper than 2H:1V.

### E.1.1.3 Materials

**<u>Channel Stabilization</u>**

Grassed Channels and Swales require non-erosive peak runoff velocities and shear stresses. Ensure the channel dimensions are capable of providing non-erosive flow rates and shear stresses. If non-erosive flow rates and shear stresses are not achieved, select an appropriate Permanent Turf Reinforcement Matting (TRM) designed to provide non-erosive conditions. Do not use Temporary Erosion Control Blanket (ECB) for permanent channel stabilization of channels with erosive flow rates or shear stresses, as they will degrade over time and lose their long-term effectiveness.

**Table E.4: TRM Material Specifications**

| Material | Specification |
|---|---|
| Turf Reinforcement Matting (TRM) | Use a TRM meeting appropriate design velocities and shear stresses. |

**Forebay**

Provide pre-treatment of concentrated runoff to Grassed Channels and Swales with a Forebay or energy dissipater where applicable. Forebays are typically provided by constructing a rock dam at the pipe inlet or concentrated flow inlet to the swale. Protect Forebay inlets to reduce erosive forces of the runoff. The preferable protective material is TRM.

**Earthen Flow Control Structures**

The body of the earthen flow control structures is composed of an earth berm stabilized with permanent grass and ECB.

### E.1.1.4 Construction Requirements

**Site Preparation**

Do not install Grassed Channels and Swales when the contributing area is not completely stabilized or is periodically being disturbed.

**Excavation**

Ensure excavation minimizes the compaction of the bottom of Grassed Channels and Swales. Operate excavators and backhoes on the ground adjacent to Grassed Channels and Swales or use low ground-contact pressure equipment. Do not operate heavy equipment on the bottom of Grassed Channels and Swales.

**Surface**

Install Grassed Channels and Swales with a minimum bottom width of two (2) feet where applicable to ensure an adequate filtration area. V-shaped ditches shall not be used. Install grass channel side slopes with an optimal slope of 3H:1V for ease of maintenance and for side inflow to remain as sheet flow. When site constraints are restrictive, the maximum side slopes are 2H:1V.

Install Grassed Channels and Swales with an optimal surface channel slope ranging from 1% to 2%, forcing a slow and shallow flow. This aspect of grassed channels allows particulates to settle out of the runoff and limits erosion.

Flow can enter Grassed Channels and Swales through a pre-treatment Forebay or it may enter along the sides of the channel through a vegetated filter strip (such as a vegetated road shoulder) as sheet along the top of the bank.

**Grass**

Plant all Grassed Channels and Swales with permanent turf type grasses according to SCDOT *Supplemental Technical Specification for Seeding SC-M-810-2* or latest revision.

**Earthen Flow Control Structure**

Install earthen flow control structures 0.5 feet high in Grassed Channels and Swales with a minimum flow length of 100-feet according to Table E.1. If site constraints do not allow 100-

feet, Grassed Channels and Swales with a slope less than or equal to 1% and a DOT ROW drainage area less than or equal to 0.5 acres may be 75-feet long with a minimum of five 0.5 ft. high earthen flow control structures installed.

The body of the earthen flow control structure shall be installed using grassed earthen berms to a height 0.5 feet above the channel bottom with a minimum top flow length of one (1) feet. The upstream and downstream slopes of the earthen flow control structure should not be steeper than 2H:1V. Stabilize the earthen flow control structure with grass and ECB where applicable.

**Outlet Structures**

Discharge stormwater runoff from Grassed Channels and Swales to a storm drainage system, or discharge to a stable protected outlet point.

### E.1.1.5 Inspection and Maintenance

Regular inspection and maintenance is critical to the effective operation of Grassed Channels and Swales. Typical maintenance responsibilities include:

- Mow grass within Grassed Channels and Swales at least once during the growing season to a height of approximately six (6) inches.
- Repair and replace earthen flow control structures as necessary.
- Repair erosion, rills, and gullies.
- Remove accumulated sediment as necessary.
- Grassed Channels and Swales may periodically require aeration of the channel bed in order to increase the permeability of the system.

**Table E.5: Grassed Channels and Swales Maintenance Requirements**

| Required Maintenance | Frequency |
|---|---|
| Mow grass to maintain design height and remove clippings | As needed (frequent/seasonally) |
| Nutrient and pesticide management | Annual, or as needed |
| Inspect side slopes for erosion and repair | Annual, or as needed |
| Inspect channel bottom for erosion and repair | Annual, or as needed |
| Remove trash and debris accumulated in Forebay | Annual |
| Inspect vegetation and plant an alternative grass species if original permanent cover is not established | Annual (semi-annually first year) |
| Inspect for channel blockage and correct the problem | As Needed |
| Aeration of the surface of the bed when the grass channel does not draw down in 48 hours | As Needed |
| Remove sediment build-up within the bottom of the grass channel | As needed, after 25% of the original design volume has filled. |

### E.1.2 Vegetated Filter Strips

#### E.1.2.1 Description

Vegetated channels, vegetated swales, and vegetated filter strips are the primary water quality BMPs utilized by SCDOT.

Vegetated filter strips are used to treat runoff from roadways. Runoff enters the vegetated filter strip as overland sheet flow spread out over the width of the strip at a shallow depth. Typical vegetated filter strips include vegetated roadside shoulders.

#### E.1.2.2 Design Requirements

Slopes between 2% and 10% are recommended for vegetated of the filter strips, but they can be effective in treating highway runoff at steeper slopes.

If the vegetative cover drops below 80 percent, the pollutant removal ability the vegetated filter strip falls off dramatically (Barret et al., 2004). Do not use vegetated filter strips where a dense turf grass cover cannot be sustained.

Filter strips should be at least four (4) feet long. The top and toe of the slope should be flat to encourage sheet flow if a flow spreader is not required.

A water quality modeling study for SCDOT comparing the pollutant removal capabilities of vegetated filter strips adjacent to roadways (vegetated shoulders and medians) determined that vegetated filter strips with greater than 80 percent vegetation coverage, reduced annual loads of TSS and dissolved metals by 80%. The vegetated filter strips widths are prescribed based on width of roadway draining and the slope of the vegetated filter strips. In cases where a minimum VFS width of four (4) feet cannot be met due to area or slope considerations, a VFS width of two (2) feet may be used for 12 feet of roadway. Specify vegetated filter strips according to Table E.6.

**Table E.6: Vegetated Filter Strip Design Widths for 80% Annual TSS Trapping**

| Width of Road Draining to Filter Strip (ft) | Minimum Width of VFS (ft) | |
|---|---|---|
| | Upper State | Lower State |
| 12* | 4* | 4* |
| 24 | 8 | 6 |
| 36 | 16 | 10 |

**If 4 feet of VFS is not possible, 2 feet may be used.*

#### E.1.2.3 Construction Requirements

**<u>Grass</u>**

Plant all Vegetated Filter Strips with the seeding schedule for shoulders and medians according to SCDOT *Supplemental Technical Specification for Seeding SC-M-810-2* or latest revision.

### E.1.2.4 Inspection and Maintenance

Regular inspection and maintenance is critical to the effective operation of a Vegetated Filter Strip.

**Preventive Maintenance and Operation Activities**

The following list includes reoccurring maintenance and operation activities that are required to maintain a functional filter strip.

- Once a year, re-seed the Vegetated Filter Strip with primary turf-type vegetation to maintain a dense growth of vegetation.
- Maintain a stable ground cover in the drainage area to reduce the sediment load to the vegetation.
- Mow Vegetated Filter Strip as needed during the growing season. Turf grass should not be cut shorter than three (3) inches and may be allowed to grow as tall as 12 inches depending on aesthetic requirements.
- Aerate the Vegetated Filter Strip once a year where applicable.
- Once a year, perform a soil test and add lime and fertilizer as required.

**Intermittent Maintenance and Repairs**

Table E.7 includes typical intermittent maintenance needs and repairs with remediation suggestions for each potential problem.

**Table E.7: Vegetated Filter Strip Maintenance and Repairs**

| Potential Problem | How to Remediate the Problem |
|---|---|
| Trash/debris is present | Remove the trash/debris. |
| Grass is too short or too long (if applicable) | Maintain grass at a height of approximately 3 to 6 inches. |
| Areas of bare soil and/or erosive gullies have formed | Re-grade the soil if necessary to remove the gully, and then plant a ground cover and water until it is established. Provide lime and a one-time fertilizer application. |
| Sediment is building up on the filter strip | Remove the sediment and re-stabilize the soil with vegetation if necessary. Provide lime and a one-time fertilizer application. |
| Grass is dead, diseased, or dying | Determine the source of the problem: soils, hydrology, disease, etc. Remedy the problem and replace vegetation. Provide a one-time fertilizer application. |
| Nuisance vegetation is choking out grass | Remove vegetation by hand if possible. If pesticide is used, do not allow it to get into the receiving water. |

### E.1.3 Dissolved Oxygen Enhancement Structures

#### E.1.3.1 Description

Vegetated channels, grassed swales, and filter strips are the primary water quality BMPs utilized by SCDOT. Dissolved Oxygen Enhancement Structures are enhanced riprap structures and aeration pads which provide aeration of stormwater runoff as it flows through and across the structure, causing an increase to dissolved oxygen levels. Use Dissolved Oxygen Enhancement Structures in medians and drainage conveyance swales or ditches as an enhancement to vegetated swales when discharging to water bodies impaired for Dissolved Oxygen (DO). Dissolved Oxygen Enhancement Structures are used to improve water quality and do not provide stormwater runoff volume control.

#### E.1.3.2 Design Requirements

Design Dissolved Oxygen Enhancement Structures to treat the runoff from the entire drainage basin. Typical Dissolved Oxygen Enhancement Structures have a minimum bottom width between two (2) and eight (8) feet. Exact dimensions will be dictated by channel dimensions. See SCDOT Standard Drawing 815-007-00 for dimensions and design guidance.

Flow enters Dissolved Oxygen Enhancement Structures through conveyance channels. Place enhanced riprap structures perpendicular to the flow path to promote aeration of stormwater flows.

When a Dissolved Oxygen Enhancement Structure is designed to be an online structure, the Dissolved Oxygen Enhancement Structure must be able to safely pass runoff for the 10-year, 24-hour storm event.

#### E.1.3.3 Materials

Dissolved Oxygen Enhancement Structures consist of enhanced riprap flow control structures, an aeration pad, and a stabilized outlet.

**Table E.8: Dissolved Oxygen Enhancement Structure Material Specifications**

| Material | Specification |
|---|---|
| Enhanced Riprap Structures | Use Class C riprap. |
| Aeration Pad | Use Class A riprap. |
| Non-Woven Geotextile Fabric | Use Class 2 Type C non-woven geotextile fabric. |
| Turf Reinforcement Matting (TRM) | Use a TRM that conforms with *Supplemental Technical Specification for RECPs (SC-M-815-9)*, or latest revision, for Turf Reinforcement Matting (TRM) description, materials, and construction requirements. |

**Enhanced Riprap Structures**

Place enhanced riprap structures perpendicular to the flow path to promote aeration of stormwater flows. Enhanced riprap structures consist of a weir structure constructed of Class C riprap with a downstream aeration pad constructed of Class A riprap. Use a Class 2 Type C non-woven geotextile fabric under all riprap structures.

### E.1.3.4 Construction Requirements

**Installation**

Do not install Dissolved Oxygen Enhancement Structures on sites where the contributing area is not completely stabilized or is periodically being disturbed.

Ensure installation minimizes the compaction of the bottom of Dissolved Oxygen Enhancement Structures. Operate excavators and backhoes on the ground adjacent to Dissolved Oxygen Enhancement Structures or use low ground-contact pressure equipment. Do not operate heavy equipment on the bottom of Dissolved Oxygen Enhancement Structures.

**Enhanced Riprap Structures**

Place enhanced riprap structure perpendicular to the flow path to promote aeration. Install an aeration pad on the downstream side of the structure. Place the enhanced riprap structure at the final stormwater runoff outfall point prior to the discharge to the receiving water body.

**Outlet Structures**

Discharge runoff from Dissolved Oxygen Enhancement Structures to a stabilized outlet point.

### E.1.3.5 Inspection and Maintenance

Regular inspection and maintenance is critical to the effective operation of Dissolved Oxygen Enhancement Structures. Typical maintenance responsibilities include:

- Keep a record of average de-watering time to determine if maintenance is required.
- Remove trash and debris periodically as needed.
- Remove sediment build-up as needed.

**Table E.9: Dissolved Oxygen Enhancement Structure Maintenance Requirements**

| Required Maintenance | Frequency |
|---|---|
| Inspect side slopes for erosion and repair | Annual, or as needed |
| Inspect stabilized outlet for erosion and repair | Annual, or as needed |
| Remove trash and debris | Annual |
| Inspect for clogging and correct the problem | Annual |
| Remove sediment build-up upstream of the Dissolved Oxygen Enhancement Structure | As needed, after 25% of the original design volume has filled. |

### E.1.4 Dry Detention Basins

#### E.1.4.1 Description

A dry detention basin does not maintain a permanent pool and is intended to manage both the quantity and quality of stormwater runoff before discharging. Stormwater runoff enters a dry detention basin through one or more inlets that discharge into a Forebay that is designed to settle out larger sediment. The runoff then passes over a forebay berm and into the main dry detention basin. Runoff exits the basin through the principal spillway. In the case of extreme rainfall events, an emergency spillway is included in the design in order to safely pass high flow rates.

#### E.1.4.2 Design Requirements

To achieve 80% removal efficiency of the average annual post-development TSS load, the temporary water quality pool volume of a dry detention basin is designed to treat the water quality volume which is:

- One (1) inch of runoff from the drainage area;
- Within half a mile of a receiving water body in the Coastal Zone, ½ inch of runoff from the entire Project site or the first one (1) inch of runoff from the built-upon portions of the Project, whichever is greater; or
- 1.5 inches of runoff from built-upon portions of the Project within 1,000 feet of shellfish beds.

Each dry detention basin must be able to hold the water quality volume and release this volume over a minimum period of 24 hours. This is achieved through an outlet orifice or other low flow control device.

In addition to detention volume, the design must provide for sediment storage equal to 25 percent of detention volume. Provide additional sediment storage if the upstream drainage basin will contribute high sediment loads over several years.

**Converting Sediment Basins to Dry Detention Basins (Multipurpose Basins)**

Sediment basins that are used during construction can be converted into dry detention basins after the construction is completed. If used during construction as a sediment basin, completely clean out the basin, re-grade, and vegetate with permanent vegetation within 14 days of completion of construction. When the construction phase has ended, remove the woven wire fence and install security fence per SCDOT Specification Section 806.

**Site Selection**

Ensure the seasonally high groundwater table is at least two (2) feet below the bottom of the basin. Less separation distance makes the dry extended detention basin vulnerable to developing ephemeral pools of standing water during wet-weather periods. If the 2-foot minimum separation distance cannot be met, consider the design of a wet detention basin.

## Basin Geometry

The volume of a dry detention basin is driven exclusively by the volume of stormwater that is required to be captured. Once that volume is calculated, the dimensional aspect of the basin is mostly site driven. Utilize the following dimensional and layout requirements:

- The maximum depth is 10 feet without requiring a Geotechnical slope stability analysis.
- The Dry Basin bottom has a minimum slope of 0.5% and an optimal slope of 2%.
- Ensure there are no depressions in a dry detention facility where water might pocket after the water level has receded.
- Dry detention systems are designed to completely drain within three (3) days.
- Design the 100-year water surface elevation a minimum of 1.0 feet below the top of the dam embankment.
- The minimum flow length to width ratio is 2:1, but 3:1 is recommended. The basin width preferably expands as it approaches the outlet.
- Side slopes of the basin are no steeper than 2H:1V if stabilized by vegetation.
- Direct the discharge from the basin to a stable channel or outlet.

Minimize flow short-circuiting as it causes turbulence and eddies in the flow, and can interfere with the function of the basin outlet system. The most direct way of minimizing short-circuiting is to maximize the distance between the riser and the inlet(s). Provide larger length to width ratios if sedimentation of particulates during low flows is desirable. Irregularly shaped basins appear more natural. If a relatively long, narrow facility is not suitable at a given site, permanent baffles constructed from gabions or other materials can be placed in the basin to lengthen the flow length.

## Flow Length

For maximum dry detention basin water quality benefits, the optimal ratio of flow length to flow width is 3L:1W. Due to site constraints, the minimum allowable design ratio of flow length to flow width is 1.5L:1W. To increase the basin flow length to flow width ratio, the basin may be designed with baffles.

Design dry detention basins in a wedge-shape (when practicable) with the widest cross sections occurring at the downstream end of the basin.

## Dry Basin Bottom Requirements

Grade the dry detention basin bottom towards the outlet structure to prevent standing water conditions and stabilize to prevent scour. A minimum 0.5% and optimal 2% bottom slope is recommended for both cross slope and longitudinal slope. If the 2% grade cannot be obtained, consider installing an under drain. Install the under drain in the following manner:

- The under drain is one of the last items installed to eliminate any sediment build-up causing the under drain to not function properly.
- Install a non-woven geotextile fabric in the excavated trench first.
- Install a perforated drain pipe covered with washed stone.
- Wrap both the stone and perforated drain pipe with the non-woven geotextile and backfill with sandy porous material.

**Low Flow Channel**

Low flow channels may be used for dry basins in areas with low permeable soils. Install a low flow channel to prevent standing water conditions when the pond bottom may be subject to non-storm flow from groundwater, footing drainage, storm sewer acting as under drain, and sump discharge. Stabilize the low flow channel using Class B riprap with an underlying filter fabric, a TRM, or concrete. The upstream side of the low flow channel starts downstream of the forebay and extends to the outlet structure. Low flow channels are not recommended for basins with highly permeable soils.

**Low Flow Orifice for Basin Dewatering**

Use a low flow orifice or dewatering device to slowly release the water quality volume over a minimum period of 24 hours depending upon the design criteria for the water quality structure. Dry basins with slow release rates for water quality control require a small orifice at the bottom of the outlet control structure with a minimum size of two (2) inches. These structures are prone to becoming clogged. Ensure the low flow orifice is protected from clogging by designing appropriate trash guards. Acceptable low flow or dewatering methods include orifices with trash boxes made of sturdy wire mesh or Floating Skimmers.

**Forebay**

The function of the Forebay is to trap the majority of the coarse fractions of the suspended solids in the runoff before it enters the main dry detention area.

Design the Forebay volume (or combined volume of Forebays) equal to a minimum of 10 percent of the overall water quality treatment volume. Each Forebay is sized according to the outlets contribution to the basin. Provide a Forebay for all inlets to a dry detention basin and place Forebays upstream of the main dry detention area. A Forebay is not required for an outlet that contributes less than 10% of the total drainage area to the basin.

Design Forebay side slopes to be 2H:1V or flatter.

The Forebay is separated from the larger dry detention basin area by berms, barriers, or permanent baffles that may be constructed of earth, stones, riprap, gabions, or geotextiles. The berm, barrier, or permanent baffles act as a trap for coarse sediments and minimize their movement into the main detention basin.

Design the Forebay in a manner that it is accessible for easy cleanout because it will eventually fill in with coarse particles. Design the access to the Forebay with a maximum slope of 15-20 percent extending from the top of the embankment to the toe.

**Principal Spillway**

Design the principal spillway to safely pass, at a minimum, the 10-year, 24-hour storm event. Design the principal spillway with a trash rack to control clogging by debris and to provide safety to the public. Ensure the riser is installed with anti-floatation measures to prevent the riser floating.

**Emergency Spillway**

Design a stabilized emergency spillway to safely pass the post-development 100-year, 24-hour storm event without overtopping any dam structures. Design the 100-year water surface elevation a minimum of 1.0 feet below the top of the dam embankment.

### E.1.4.3 Installation

Perform the following for dry detention basin installation requirements:

1. Route all channels and pipes conveying flow to the basin away from the basin area until the basin is complete and stabilized.
2. Clear, grub, and strip the area under the embankment of all vegetation and root mat. Remove all surface soil containing high amounts of organic matter and stockpile or dispose of it properly. Remove all unused fill material to the designated disposal area.
3. Ensure that fill material for the embankment is free of roots, woody vegetation, organic matter, and other objectionable material. Place the fill in lifts not to exceed nine (9) inches, and machine compact it. Over fill the embankment six (6) inches to allow for settlement.
4. Install inlet and outlet control structures. Ensure principal spillway and emergency spillway installed to proper elevations as specified in the engineering drawings.
5. Grade the basin with a slope towards the outlet structure to ensure basin dewatering.
6. Install forebay and erosion control at basin inlets/outlets.
7. Stabilize all berms and embankments in accordance with the Seeding specification.
8. Route flow from contributing watershed to the dry detention basin as shown in the engineering drawings.
9. Follow required maintenance guidelines.

### E.1.4.4 Inspection and Maintenance

Regular inspection and maintenance is critical to the effective operation of a dry detention basin. Proper maintenance ensures the continued functionality of the dry detention basin. Table E.10 outlines various maintenance requirements after the installation of a dry detention basin.

**Table E.10: Dry Basin Maintenance Requirements**

| Required Maintenance | Frequency |
|---|---|
| Clean and remove debris from inlet and outlet structures | After large storm events |
| Mow side slopes | As needed |
| Removal of invasive vegetation | Semi-annual |
| Inspect for damage to outlet control structure | Annual |
| Inspect for sediment accumulation in the basin and forebay | Annual |
| Inspect for operational inlet and outlet structures | Annual |
| Repair embankment, side slopes, undercut, or eroded areas | Annual, or as needed |
| Pesticide/ Nutrient management | Annual, or as needed |
| Remove sediment from the forebay | Per design cycle (typical 5-10 year maintenance) after 50% of total forebay capacity is filled |
| Remove sediment accumulations from the main permanent pool | Per design cycle (typical 5-10 year maintenance) after 25% of permanent pool volume is filled |

## E.1.5 Wet Detention Basins

### E.1.5.1 Description

A wet detention basin can manage both the quantity and quality of stormwater runoff before discharging off-site. The minimum drainage area for wet detention ponds ranges from 10-25 acres, depending on the specific wet detention application.

Stormwater runoff enters a wet detention basin through one or more inlets that discharge into a Forebay that is designed to settle out larger sediment. The runoff then passes over a forebay berm and into the main wet detention basin, becoming part of a combined temporary and permanent storage. The temporary water quality storage volume drains from the wet detention basin over a minimum period of 24 hours. Permanent storage remains in the wet detention basin, where natural processes facilitate both settling and nutrient reduction of the water contained within the wet detention basin.

Wet detention basins are applicable where larger developments in a watershed substantially modify the hydrology and pollutant loading of a watershed. Because wet detention basins are area-intensive, their use in drainage areas smaller than 10 acres is not recommended.

### E.1.5.2 Design Requirements

If the underlying soil is Hydrologic Soil Group A, B, or C, an infiltration test on the wet detention basin bottom must be conducted. If the infiltration rate exceeds 0.01inches/hour, a liner or clay pack is required.

The design of a wet detention basin can be divided into three components of volume: Forebay volume, permanent pool volume, and temporary water quality pool volume.

**Flow Length**

For maximum wet detention basin water quality benefits, the optimal ratio of flow length to flow width is 3L:1W. Due to site constraints, the minimum allowable design ratio of flow length to flow width is 1.5L:1W. To increase the pond's flow length to flow width ratio, the basin may be designed with baffles.

Optimizing the wet basin flow shape and flow distance through the pond promotes better water quality treatment. Settling is the primary pollutant removal mechanism sought when addressing flow length as a water quality design feature. Wet detention basins designed with optimum flow lengths will avoid the problem of dead storage or incoming runoff short circuiting through the pond. Optimum flow lengths will also decrease the turbulence within the basin and minimize the re-suspension of deposited sediments.

Design wet detention basins in a wedge-shape (when practicable) with the widest cross sections occurring at the downstream end of the basin. Design the deepest pools at the downstream end of the basins to help facilitate cooler effluent water temperatures.

## Permanent Pool Volume

To achieve 80% removal efficiency of the average annual post-development TSS load, wet detention basins are designed to have minimum permanent pool volume equal to:

- ½ inch of runoff from the drainage area;
- Within ½ mile of a receiving water body in the Coastal Zone, ½ inch of runoff from the entire Project site or the first one (1) inch of runoff from the built-upon portions of the Project, whichever is greater; or
- 1.5 inches of runoff from built-upon portions of the Project within 1,000 feet of shellfish beds.

Design the permanent pool with an optimal depth between four (4) and six (6) feet, with a minimum depth of four (4) feet and a maximum depth of 12 feet. Ensure the bottom of the basin is located at least two (2) feet from the seasonally high water table.

## Temporary Water Quality Pool Volume

The temporary water quality volume is ½ inch of runoff from the drainage area or **1.5 inches** for projects within 1,000 feet of shellfish beds. Each wet detention basin must be able to hold the water quality volume above the permanent pool and release this volume over a minimum period of 24 hours. This is achieved through an outlet orifice or other flow control device.

## Low Flow Orifice

Use a low flow orifice to slowly release the water quality volume over a minimum period of 24 hours depending upon the design criteria for the water quality structure. Wet ponds with slow release rates for water quality control require small outlet control structures. These structures are prone to becoming clogged. Ensure the low flow orifice is protected from clogging by designing appropriate trash guards.

Acceptable trash guards include:

- Trash boxes made of sturdy wire mesh that cover the low flow orifice.
- Floating Skimmers
- Hoods that extend at least six (6) inches below the permanent pool water surface elevation.
- Reverse flow pipes where the outlet structure inlet is located below the permanent pool water surface elevation.
- Hoods or Reverse flow pipes are required for wet extended basins and micropool extended basins.

**Forebay**

The function of the Forebay is to trap the majority of the coarse fractions of the suspended solids in the runoff before it enters the main wet detention area, therefore allowing the main pond to maintain its original design volume

Design the Forebay volume (or combined volume of Forebays) equal to a minimum of 10 percent of the overall water quality treatment volume. Each Forebay is sized according to the corresponding outlet’s contribution to the basin. Provide a Forebay for all inlets to a wet detention basin and place Forebays upstream of the main wet detention area. A Forebay is not required for an outlet that contributes less than 10% of the total drainage area or to the basin.

Design Forebay side slopes to be 2H:1V or flatter.

The Forebay is separated from the larger wet detention basin area by berms, barriers, or permanent baffles that may be constructed of earth, stones, riprap, gabions, or geotextiles. The berm, barrier, or permanent baffles act as a trap for coarse sediments and minimize their movement into the main detention basin. The Forebay berm may incorporate a drain pipe or be constructed of riprap to facilitate equalization of the pond over time.

Design the top of the Forebay barrier a maximum of one (1) foot below the permanent pool elevation and it may extend above the elevation of the permanent pool.

Design the Forebay depth, as measured from the maximum water quality event surface level, between four (4) and six (6) feet. To minimize the re-suspension of settled particles, design the minimum permanent pool depth of water in the Forebay three (3) feet above the design sediment storage elevation.

Design the Forebay in a manner that it is accessible for easy cleanout because it will eventually fill in with coarse particles. Design the access to the Forebay with a maximum slope of 15-20 percent extending from the top of the embankment to the toe

**Principal Spillway**

Design the principal spillway to safely pass, at a minimum, the 10-year, 24-hour storm event. Design the principal spillway with a trash rack.

A level spreader may be installed at the wet detention basin outlet structure to prevent destabilization of the receiving water body. The installation of a 30-foot wide filter strip beyond the level spreader is recommended.

**Emergency Spillway**

Design emergency spillways to safely pass the post-development 100-year, 24-hour storm event without overtopping any dam structures. Design the 100-year water surface elevation a minimum of one (1) foot below the top of the dam embankment.

### E.1.5.3 Installation

Perform the following for all Wet Detention Basin installations:

1. Route all channels and pipes conveying flow to the basin away from the basin area until the basin is complete and stabilized.
2. Clear, grub, and strip the area under the embankment of all vegetation and root mat. Remove all surface soil containing high amounts of organic matter and stockpile or dispose of it properly. Remove all unused fill material to the designated disposal area.
3. Ensure that fill material for the embankment is free of roots, woody vegetation, organic matter, and other objectionable material. Place the fill in lifts not to exceed nine (9) inches and machine compact it. Over fill the embankment six (6) inches to allow for settlement.
4. Install inlet and outlet control structures. Ensure principal spillway and emergency spillway installed to proper elevations as specified in the engineering drawings.
5. Grade the basin so that the bottom is level front to back and side to side and prepare subsoil.
6. Apply and grade planting soil for wet extended aquatic bench.
7. Install forebay and erosion control at pond inlets/outlets.
8. Seed, plant, and mulch the embankments and the wet extended aquatic bench.
9. Route flow from contributing watershed to the basin as shown in the engineering drawings.
10. Follow required maintenance guidelines.

### E.1.5.4 Inspection and Maintenance

Regular inspection and maintenance is critical to the effective operation of a wet detention basin. Proper maintenance ensures the continued functionality of the wet detention basin. Table E.11 outlines the various maintenance requirements after the installation of a wet detention basin.

**Table E.11: Wet Basin Maintenance Requirements**

| Required Maintenance | Frequency |
|---|---|
| Clean and remove debris from inlet and outlet structures | After large storm events |
| Mow side slopes | As needed |
| Removal of invasive vegetation | Semi-annual |
| Inspect for damage to outlet control structure | Annual |
| Inspect for sediment accumulation in the basin and forebay | Annual |
| Inspect for operational inlet and outlet structures | Annual |
| Repair embankment, side slopes, undercut or eroded areas | Annual, or as needed |
| Perform wetland plant management and harvesting | Annual |
| Pesticide/ Nutrient management | Annual, or as Needed |
| Remove sediment from the forebay | Per design cycle (typical 5-10 year maintenance), after 50% of total forebay capacity is filled |
| Remove sediment accumulations from the main permanent pool | Per design cycle, (typical 5-10 year maintenance) after 25% of permanent pool volume is filled |

### E.1.6 Infiltration Trenches

#### E.1.6.1 Description

Infiltration Trenches are excavations filled with stone to create an underground reservoir to manage stormwater runoff. Use individual Infiltration Trenches for drainage areas up to two (2) acres in size.

The stormwater runoff volume enters the Infiltration Trench, is temporarily stored, and gradually exfiltrates through the bottom and sides of the trench into the subsoil. Infiltration Trenches fully de-water within a 24- to 72-hour period depending on trench dimensions, soil type, and underdrain system.

Use Infiltration Trenches to capture sheet flow from a drainage area or function as an off-line device. Due to the relatively narrow shape, Infiltration Trenches can be adapted to many different types of sites and can be utilized in retrofit situations. Because Infiltration Trenches are sensitive to fine sediments, do not install them on sites where the contributing area is not completely stabilized or is periodically being disturbed.

Infiltration Trenches are limited to areas with highly porous soils where the water table and or bedrock are located well below the trench bottom. Infiltration Trenches:

- Are only applicable for Hydrologic Soil Group A soils, or soils that have a minimum infiltration rate of 0.5 inches per hour determined from site specific soil boring samples.
- Are located to avoid ground water contamination.
- Are not intended to trap sediment during construction activities.
- Have a sediment forebay or other pre-treatment measure to prevent clogging in the gravel.
- Have an overflow system to provide non-erosive flow velocity along the length and at the outfall.
- Are applicable for impervious areas where there are low levels of fine particulates in the runoff and the site is completely stabilized and the potential for possible sediment loads are very low.

#### E.1.6.2 Design Requirements

To achieve 80% removal efficiency of the average annual post-development TSS, Infiltration Trenches are designed to have a water quality volume equal to:

- One (1) inch of runoff from impervious areas located on the Project site, or
- 1.5 inches of runoff from built-upon portions of the Project within 1,000 feet of shellfish beds.

Calculate the Infiltration Trench area using the following equation:

$$A = \frac{V}{\left(nd + \frac{kT}{12}\right)}$$

Where:

- ***A*** = Surface area of Infiltration Trench (feet$^2$)
- ***V*** = Water Quality volume (1 inch or 1.5 inches)
- ***n*** = Porosity of stone in infiltration trench (0.3 to 0.5 depending on stone)

  *Use a porosity value (**n**) of 0.32 unless an aggregate specific value is known.*
- ***d*** = Depth of trench (feet)
- ***k*** = Infiltration rate of soil (inches/hour)
- ***T*** = Fill time (hours). A fill time of 2 hours is recommended for most design calculations.

### E.1.6.3 Materials

**Stone Fill**

The stone fill media consists of 1.0- to 2.5-inch $D_{50}$ clean crushed stone with six (6) inches of pea gravel located on top separated by a Class 2 Type C permeable nonwoven geotextile filter fabric.

**Permeable Nonwoven Geotextile Fabric**

Place a permeable nonwoven geotextile filter fabric between the pea gravel and stone fill and the stone fill and adjacent soil. The filter fabric prevents sediment from passing into the stone media and is easily separated from the nonwoven geotextile fabric that protects the sides of the excavated trench.

**Sand Filter**

Place a 6-inch sand filter or Class 2 Type C permeable nonwoven filter fabric on the bottom of the trench.

**Observation Well**

Install observation wells spaced a maximum of 100 feet in every Infiltration Trench. The well is made of 4- to 6-inch PVC pipe. Extend the observation well to the bottom of the trench. The observation well shows the rate of de-watering after a storm event and predicts when maintenance is required for the Infiltration Trench. Install the observation well along the centerline of the trench, flush with the ground elevation of the trench. Cap the top of the well to discourage vandalism and tampering.

**Table E.12: Infiltration Trench Material Specifications**

| Material | Specification |
|---|---|
| No. 57 Aggregate | Use course aggregate No. 57 consisting of crushed slag or gravel |
| 1.0- to 2.5-inch $D_{50}$ Crushed Stone | Coarse Aggregate Size No.: 2, 24 or 3 |
| Pea Gravel | ASTM D 448; Stone Size No. 6 or 1/8” to 3/8” |
| Sand Filter Material | AASHTO Std. M-43, Size No. 9 or No. 10) (SCDOT FA-10 Size No. 8) |
| Pipe Underdrains | Use perforated pipe underdrains with a minimum diameter of 4 inches |
| Observation Well and Outlet Pipe | Use non-perforated pipe underdrains with a minimum diameter of 4 inches |
| Class 2 Type C Permeable Non-Woven Geotextile Fabric | Use Class 2 Type C non-woven geotextile fabric |

### E.1.6.4 Construction Requirements

Ensure stormwater runoff from areas draining to Infiltration Trenches passes through stabilized vegetated filter at least 20 feet in length, a sediment Forebay, or other pre-treatment measure before discharging to the Infiltration Trench. Do not install Infiltration Trenches in fill material because piping along the fill and natural ground interface may cause slope failure.

**Site Preparation**

Ensure a vertical distance of four (4) feet between the Infiltration Trench bottom and the elevation of the seasonally high water table, whether perched or regional. The water table is determined by direct piezometer measurements and on-site soil borings.

Locate Infiltration Trenches greater than three (3) feet deep a minimum of 10 feet from basement walls.

Locate Infiltration Trenches a minimum of 150 feet from any public or private water supply well.

Construct Infiltration Trenches with a maximum width of 25 feet.

**Installation**

Perform the following for all Infiltration Trench installations:

1. Construct an excavated trench with a minimum depth of three (3) feet and a maximum depth of eight (8) feet. The maximum slope bottom of the infiltration practice is five (5) percent.

2. Do not install Infiltration Trenches in fill material as piping along the fill/natural ground interface may cause slope failure.

3. Do not install an Infiltration Trench on or atop a slope whose natural angle of incline exceeds 20 percent.

4. Line the excavated trench with a permeable nonwoven geotextile filter fabric.
5. Place a 6-inch sand filter on the bottom of the trench and place a permeable geotextile filter fabric over the sand filter.
6. Install observation wells spaced a maximum of 100 feet. Extend the well to the bottom of the trench.
7. Install the observation well along the centerline of the trench, and flush with the ground elevation of the trench. Cap the top of the well to discourage vandalism and tampering.
8. Place the crushed stone fill media to a depth of six (6) inches below the top ground surface and place a permeable geotextile filter fabric over the crushed stone. Install this permeable filter fabric so it is easily separated from the geotextile filter fabric that protects the sides of the excavated trench.
9. Place six (6) inches of pea gravel on top of the crushed stone.

### E.1.6.5 Inspection and Maintenance

Regular inspection and maintenance is critical to the effective operation of Infiltration Trenches. Typical maintenance responsibilities include:

- Keeping a record of the average de-watering time of the Infiltration Trench to determine if maintenance is required.
- Replacing the top 6-inch layer of pea gravel and the permeable nonwoven geotextile filter fabric separating the pea gravel from the stone media when they become full of sediment.
- Clearing debris and trash from all inlet and outlet structures monthly.
- Checking the observation wells after three consecutive days of dry weather after a rainfall event. If complete de-watering is not observed within this period, there may be clogging within the trench and proper maintenance is required.
- Removing trees, shrubs, or invasive vegetation semi-annually.
- If complete failure is observed, performing total rehabilitation of the trench by excavating the trench walls to expose clean soil, and replacing the gravel, geotextile filter fabric, and topsoil.

**Table E.13: Infiltration Trench Maintenance Requirements**

| Required Maintenance | Frequency |
|---|---|
| Ensure that the contributing area is stabilized with no active erosion. | Monthly |
| Mow grass filter strips and remove grass clippings. | Monthly |
| Check observation wells after 72 hours of rainfall. Ensure Wells are empty after this time period. If wells have standing water, the underdrain system or outlet may be clogged. | Semi-annual (every 6 months) |
| Remove invasive vegetation. | Semi-annual (every 6 months) |
| Inspect pretreatment structures for deposited sediment. | Semi-annual (every 6 months) |
| Replace pea gravel, topsoil and top surface geotextile filter fabric. | When clogging or surface standing water is observed |
| Perform total rehabilitation of infiltration trench. | Upon observed failure |

## E.2 LIMITED APPLICATION STRUCTURAL BMPS

### E.2.1 Bioretention Areas

#### E.2.1.1 Description

Bioretention areas are stormwater basins intended to provide water quality management by filtering stormwater runoff before release into a stormwater conveyance system or stabilized outfall. Use individual Bioretention areas for drainage areas up to two (2) acres in size.

Stormwater runoff enters Bioretention areas and is temporarily stored in a shallow pond on top of a filter media layer. The ponded water then slowly filters down through the filter media and is absorbed by the plantings. As the excess water filters through the system, it is temporarily stored and collected by an underdrain system that eventually discharges to a designed storm conveyance system.

Bioretention is applicable for small sites where stormwater runoff rates are low and can be received into the Bioretention area as sheet flow. Because Bioretention areas are sensitive to fine sediments, do not install them on sites where the contributing area is not completely stabilized or is periodically being disturbed.

#### E.2.1.2 Design Requirements

**General Design Criteria**

To achieve 80% removal efficiency of the average annual post-development TSS Bioretention areas are designed to have a water quality volume equal to:

- One (1) inch of runoff from impervious areas located on the Project site, or
- 1.5 inches of runoff from built-upon portions of the Project within 1,000 feet of shellfish beds.

Design Bioretention areas to treat the water quality volume of runoff from the entire drainage basin. Bioretention areas work best when constructed off-line, capturing only the water quality volume. Divert excess runoff away from the Bioretention area or collect it with an overflow catch basin.

Design Bioretention areas to fit around natural topography and complement the surrounding landscape. Bioretention areas can be of any reasonable shape and can be fit around sensitive areas, natural vegetation, roads, driveways, and parking lots.

Typical Bioretention areas have a minimum width of ten (10) feet and a minimum flow length of 40 feet to establish a strong healthy stand of vegetation.

Where nitrogen or phosphorus is a concern, create a 90 degree elbow in the underdrain system from the bottom of the Bioretention area to create an Internal Water Storage Zone to encourage the denitrification process.

A summary of the design characteristics for Bioretention areas is shown in Table E.14.

**Table E.14: Design Characteristics for Bioretention Areas**

| | |
|---|---|
| **Drainage Area** | 0.5 to 2 acres |
| **Surface Area** | Varies, but typically 3% to 8% of the contributing watershed depending on the amount of impervious area |
| **Surface Side Slope** | 4:1 preferred, 2:1 maximum |
| **Infiltration Rate** | Between 1 and 6 inches per hour for filter media |
| **Water Depth** | Range from 6 to 12 inches with a 9-inch standard above the filter media |
| **Water Table** | Vertical distance of 3 feet between bottom of Bioretention area and seasonally high groundwater table (typically 4 to 6 feet below ground surface of the Bioretention) |
| **Places to Avoid** | Areas that regularly flood (at least once a year), areas adjacent to building foundations, and locations with continuous flow |
| **Mulches** | A minimum of 2 inches is required while 3 to 4 inches is preferable. Mulch should be hardwood, not pine bark nuggets (float). Double-shredded hardwood works well. Pine straw may be used in some areas. |
| **Underdrain Stone** | Aggregate No. 57 or No. 5 stone is preferred. Separate the gravel from the filter media with a permeable geotextile |

***Source:*** *Urban Waterways / Urban Storm Water Structural Best Management Practices (BMPs), North Carolina Extension Service, June, 1999*

The components of a well-designed bioretention area include a pre-treatment area, treatment area consisting of a ponding area, surface mulch layer and planting bed, and a gravel underdrain system separated from the planting bed by a geotextile filter.

## Surface Area

The Bioretention surface area may be calculated by the following equation from research by the North Carolina Extension Service, 1999:

$$\mathrm{BSA} = \frac{(\mathrm{DA})(Rv)}{D_{avg}}$$

Where:

***BSA*** = Bioretention surface area ($feet^2$)

***DA*** = Contributing drainage area of Bioretention area ($feet^2$)

***Rv*** = Runoff volume (feet), 0.083 feet (1 inch) or 0.125 feet (1.5 inches)

$\boldsymbol{D_{avg}}$ = Average ponding water depth above ground (feet)

The Bioretention surface area may also be calculated by the following equation from research by Prince George's County, MD:

$$\mathrm{BSA} = 0.1(Rv)(DA)$$

Where:

| | | |
|---|---|---|
| ***BSA*** | = | Bioretention surface area (feet$^2$) |
| ***0.1*** | = | Empirical conversion factor |
| ***Rv*** | = | Runoff volume (inches), 1 inch or 1.5 inches |
| ***DA*** | = | Contributing drainage area of Bioretention area (feet$^2$) |

The Bioretention surface area may be sized using the principle of Darcy's Law. For the filter media, permeability (k) of 0.5 feet/day may be used. The maximum ponding depth of the Bioretention area is 12 inches. The following equation may be used to size the surface area.

$$A_f = \frac{V\ d_f}{\left[k\left(h_f + d_f\right)\ t_f\right]}$$

Where:

| | | |
|---|---|---|
| $\boldsymbol{A_f}$ | = | Bioretention surface area (feet$^2$) |
| ***V*** | = | Water quality volume (feet$^3$) |
| $\mathbf{d_f}$ | = | Filter Media depth (feet) |
| ***k*** | = | Coefficient of permeability of filter media (<u>feet/day</u>) (0.5 recommended) |
| $\boldsymbol{h_f}$ | = | <u>Average</u> height of water above filter mix (feet) (typically 0.25 feet) |
| $\boldsymbol{t_f}$ | = | Design filter media drain time (days) (2 days is the recommended max) |

**<u>Water Draw Down Time</u>**

Design Bioretention areas to fully de-water within a 24- to 48-hour period depending on the dimensions, filter media, and underdrain system. In order to allow for proper pollutant removal, design for the ponded runoff above the Bioretention area surface to drain in a maximum of 12 hours. Design for runoff within the filter media to drain within 48 hours.

Design the underdrain system to safely pass the peak draw down flow rate of the filter media. The general equation used to determine draw down time is Darcy's Equation:

$$Q = 2.3e^{-5}\ K\ A\ \frac{\Delta H}{\Delta L}$$

Where:

| | | |
|---|---|---|
| ***Q*** | = | Flow rate through bioretention (cfs) |
| ***K*** | = | Hydraulic conductivity of the filter media (inches/hour) |
| | | (Value varies based on actual filter media used) |
| ***A*** | = | Surface area of Bioretention ($feet^2$) |
| ***ΔH*** | = | Maximum ponding depth above bottom of filter media (feet) |
| ***ΔL*** | = | Depth of filter media (feet) |

Typical hydraulic conductivity values are:

**Table E.15: General Hydraulic Conductivity of Soils**

| Soil Classification | Hydraulic Conductivity (inches/hour) |
|---|---|
| Sand | 6.0 |
| Loamy Sand | 2.0 |
| Sandy Loam | 0.5-1.0 |

***Source:*** *Urban Waterways / Urban Storm Water Structural Best Management Practices (BMPs), North Carolina Extension Service, June, 1999.*

Determining the total draw down time is a three-step process:

1. Determine the time it takes to drain the ponded water.
   - Utilize Darcy's Equation to calculate the flow rate (cfs).
   - Calculate the total ponded water volume ($feet^3$) by multiplying the Bioretention area ($feet^2$) by the ponded water depth (feet).
   - Divide the total ponded water volume ($feet^3$) by the flow rate (cfs) to calculate the time to drain the ponded water (seconds).
2. Determine the time it takes to drain the saturated filter media.
   - Calculate the total volume of water contained in the filter media ($feet^3$) by multiplying the Bioretention area ($feet^2$) by the filter media depth (feet) by the porosity (dimensionless) of the filter media.

- Divide the filter media water volume ($feet^3$) by the flow rate from Darcy's Equation (cfs) to calculate the time to drain the ponded water (seconds).

3. Add up the time to drain the ponded water with the time that it takes to drain the filter media to calculate the total Bioretention area draw down time.

#### E.2.1.3 Materials

Bioretention areas consist of an underdrain system, an internal water storage zone/ denitrifaction zone (if required), a filter media, an overflow system, plantings, a mulch layer, and a pre-treatment system.

**Underdrain System**

Place an underdrain system beneath the filter media for all Bioretention areas as many of the native soils found in South Carolina do not allow for adequate infiltration.

Provide an underdrain system that consists of continuous closed joint perforated plastic pipe underdrains with a minimum 4-inch diameter, an 8-inch minimum gravel filter layer, a nonwoven geotextile filter fabric to separate the gravel from the native soils and the gravel from the filter media, and a minimum 4-inch diameter non-perforated PVC clean out wells.

The maximum spacing of pipe underdrains is 10 feet.

Design the under drain system to safely pass the peak draw down rate calculated in the Water Draw Down Section.

**Table E.16: Underdrain Material Specifications**

| Material | Specification |
|---|---|
| Aggregate | Use course aggregate No. 57 or No. 5 consisting of crushed slag or gravel. |
| Pipe Underdrains | Use PVC perforated pipe (AASHTO M 252) underdrains with a minimum diameter of 4 inches. |
| Clean Out and Outlet Pipe | Use non-perforated pipe with a minimum diameter of 4 inches. |
| Nonwoven Geotextile Fabric | Use Class 2 Type C non-woven geotextile fabric. |

**Internal Water Storage Zone (Denitrification Zone)**

If required for enhanced nitrogen and phosphorus removal, provide an Internal Water Storage Zone sized to hold the water quality volume below the outlet of the underdrain system. A nonwoven geotextile fabric is not required between this zone and the underdrain system. Provide a nonwoven geotextile fabric between the Internal Water Storage Zone and the underlying native soil. The Internal Water Storage Zone consists of the Filter Media and the stone used in the underdrain system. Adding a suitable carbon source like wood chips to the gravel in the Internal Water Storage Zone provides a nutrition source for anaerobic microbes and can enhance the denitrification process.

Design the Internal Water Storage Zone to treat the water quality volume of runoff from the entire drainage basin. Calculate the surface area of the Internal Water Storage Zone area by dividing the water quality volume by the ponding depth (minimum 12 inches).

Provide a minimum of 12 inches of Filter Media above the maximum ponding height of the Internal Water Storage Zone.

Install a valve for dewatering the Internal Water Storage Zone if prolonged standing water occurs.

**Filter Media**

The filter media provides a medium for physical filtration for the stormwater runoff with enough organic matter content to support plant life by providing water and nutrients.

Ensure the filter media of the Bioretention area is level to allow uniform ponding over the entire area. The maximum ponding depth above the filter media is 9 to 12 inches to allow the Bioretention area to drain within a reasonable time and to prevent long periods of plant submergence. Provide a filter media with a minimum infiltration rate of 1.0 inch/hour and a maximum rate of 6.0 inches/hour. The average porosity of the filter media is approximately 0.45.

The USDA textural classification of the filter media is Loamy Sand or Sandy Loam. The filter media is furnished, and on-site soils are not acceptable. Test the filter media to meet the criteria in Table E.17.

Submit the source of the filter media and test results to the RCE prior to the start of construction of Bioretention areas. Do not add material to a stockpile of filter media once a stockpile has been sampled.

Allow sufficient time for testing. Utilize a filter media from a certified source or laboratory to reduce mobilization time and construction delays.

Use a filter media that is uniform, free of stones, stumps, roots, or other similar objects larger than two inches excluding mulch. Do not mix or dump materials or substances within the Bioretention area that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations.

Test the filter media to meet the criteria shown in Table E.18.

Should the filter media pH fall outside of the acceptable range, modify with lime (to raise pH) or iron sulfate plus sulfur (to lower pH). Uniformly mix lime or iron sulfate into the filter media prior to use in Bioretention areas.

**Table E.17: Bioretention Filter Media Material Specifications**

| Item | Percent of Total Filter Media by Weight | ASTM Sieve Size | Percent Passing by Weight |
|---|---|---|---|
| **Sand*** <br>Clean, Washed, Well Graded, No Organic Material<br>*Aggregate No. FA-10*<br>*ASTM C-33 Concrete Sand*<br>*AASHTO M-6*<br>*AASHTO M-43, No. 9 or No. 10* | 80% Max | 3/8-inch | 100 |
| | | No. 4 | 95-100 |
| | | No. 8 | 80-100 |
| | | No. 16 | 50-85 |
| | | No. 30 | 25-60 |
| | | No. 50 | 10-30 |
| | | No. 100 | 2-10 |
| | | No. 200 | 0-3 |
| **Screened Topsoil**<br>*Loamy Sand or Sandy Loam*<br>*ASTM D5268 (imported or manufactured topsoil)*<br>*Max 5% clay content* | 15% Max. | 2-inch | 100 |
| | | 1-inch | 95- 100 |
| | | No. 4 | 75-100 |
| | | No. 10 | 60-100 |
| | | No. 200 | 10-50 |
| | | 0.002-mm | 0-5 |
| Organic Matter in the form of Compost, Leaf Compost, Peat Moss or Pine bark Nursery Mix** | 5% Min | 3/8-inch | 85-100 |
| | | No. 8 | 50-80 |
| | | No. 30 | 0-40 |

***Do not use lime stone screenings.***
***** Potting grade pine bark with no particles larger than ½ inches.***

**Table E.18: Filter Media Chemical Analysis**

| Item | Criteria | Test Method |
|---|---|---|
| Corrected pH | 6.0 – 7.5 | ASTM D4972 |
| Magnesium | Minimum 32 ppm | * |
| P-Index | 0-30 | USDA Soil Test |
| Phosphorus (Phosphate - $P_2O_5$) | Not to exceed 69 ppm | * |
| Potassium ($K_2O$) | Minimum 78 ppm | * |
| Soluble Salts | Not to exceed 500 ppm | * |

***** *Use authorized soil test procedures.*

Modify the filter media with magnesium sulfate if the filter media does not meet the minimum requirement for magnesium. Modify the filter media with potash if the filter media does not meet the minimum requirement for potassium. Uniformly mix magnesium sulfate and potash into the filter media prior to use in Bioretention areas.

A filter media that fails to meet the minimum requirements must be replaced. The recommended depth of the filter media is:

**Table E.19: Bioretention Filter Media Depth**

| Vegetation | Filter Media Depth (feet) |
|---|---|
| Turf Grass Only | 2.0 |
| Native Grasses or Shrubs | 3.0 |
| Small Trees | 4.0 |

## Overflow System

Design an overflow system to pass runoff volumes greater than the water quality volume away from the Bioretention area. Place an outflow structure at the elevation of the maximum 9- to 12-inch ponding depth above the Bioretention area surface to carry excess runoff to a stormwater conveyance system or stabilized outlet.

## Plantings

Use plantings that conform to the standards of the current edition of American Standard for Nursery Stock as approved by the American Standards Institute, Inc.

For Bioretention applications near roadways, consider site distances and other safety concerns when selecting plant heights. Consider human activities which may damage the plantings, cause soil compaction, or otherwise damage the function of the Bioretention area when selecting plant species.

Use plant materials that have normal, well-developed stems or branches and a vigorous root system. Only use plantings that are healthy and free from physical defects, plant diseases, and insect pests. Symmetrically balance shade and flowering trees. Ensure major branches do not have V-shaped crotches capable of causing structural weakness. Ensure trunks are free of unhealed branch removal wounds greater than a 1-inch diameter.

Use plant species that are tolerant to wide fluctuations in soil moisture content. Use plantings capable of tolerating saturated soil conditions for the length of time anticipated for the water quality volume, as well as anticipated runoff constituents. Acceptable Bioretention area plantings include:

- Turf Grass Only - Use turfgrass species that have a thick dense cover, are slow growing, are applicable to the expected moisture conditions (dry or wet), do not require frequent mowing, and have low nutrient requirements. The preferred method of establishing turf grass is sodding. Use temporary erosion control blankets to provide temporary cover when establishing turf grass by seeding.

- Native Grasses and Perennials - Create a low maintenance native grass or wildflower meadow with native grasses and native perennial species. Temporary erosion control blankets may be used in lieu of a hardwood mulch layer. Plant native grasses and perennials of the same species in clusters 1.0 to 1.5 feet on-center.

- Shrubs - Provide shrubs a minimum of two feet in height. Do not plant shrubs near the inflow and outflow points of the Bioretention area. Plant shrubs of the same species in clusters 10 feet on-center.
- Trees - Provide trees with a minimum 1-inch caliper. Plant trees near the perimeter of the Bioretention area. Do not plant trees near the inflow and outflow points of the Bioretention area. Do not plant trees directly above Underdrains. Plant trees at a density of one tree per 250 square feet.

**Planting Plan**

A Bioretention area landscape plan includes all planting types, total number of each species, and the location of each species used. The plan includes a description of the contractor’s responsibilities including a planting schedule, installation specifications, initial maintenance, a warranty period, and expectations of plant survival. A planting plan includes long-term inspection and maintenance guidelines. Use planting plans prepared by a qualified landscape architect, botanist, or qualified extension agent. Use native plant species over non-native species. Ornamental species may be used for landscaping effect if they are not aggressive or invasive.

**Mulch Layer**

Provide a uniform 3-inch layer of mulch on the surface of the Bioretention area that provides an environment to enhance plant growth, enhance plant survival, suppresses weed growth, reduce erosion of the filter media, maintain soil moisture, trap fine sediments, promote the decomposition of organic matter, and pre-treat runoff before it reaches the filter media.

Provide shredded hardwood bark that consists of bark from hardwood trees milled and screened to a maximum 4-inch particle size, uniform in texture, free from sawdust and foreign materials, and free from any artificially introduced chemical compounds detrimental to plant life. Provide mulch that is well aged a minimum of six months.

Do not use pine needle or pine bark mulch due to the ability of floatation.

Use alternative surface covers such as native groundcover, erosion control blankets, river rock, or pea gravel as directed by the RCE. Use alternative surface covers based on function, cost, and maintenance.

Do not provide a mulch layer for Bioretention areas that utilize turf grass as the vegetation material.

**Pre-treatment System**

Provide a pre-treatment system to reduce incoming velocities, evenly spread the flow over the entire Bioretention area, and to trap coarse sediment particles before they reach the filter media. Several pre-treatment systems are applicable, depending on whether the Bioretention area receives sheet flow, shallow concentrated flow, or deeper concentrated flows. The following are appropriate pre-treatment options:

- Forebay (for channel flow): Located at pipe inlets or curb cuts leading to the Bioretention area consisting of energy dissipation and flow dispersion sized for the expected peak discharge rate. The Forebay may be formed by a wooden or stone check dam or an earthen or rock berm. Ensure the Forebay is protected with the proper erosion prevention measures. The Forebay does not require an underlying filter media.

- Grass Filter Strips (for sheet flow): Extend a minimum of 10 feet from edge of pavement to the upstream edge of the Bioretention area with a maximum slope of 5%.
- Gravel or Stone Diaphragms (for sheet or concentrated flow): Located at the edge of pavement or other inflow point, running perpendicular to the flow path to promote settling. Size the stone according to the expected peak discharge rate.
- Level Spreaders (for sheet flow): Gravel, landscape stone, or concrete level spreader located along the upstream edge of the Bioretention area. Level spreaders successfully reduce incoming energy from the runoff and convert concentrated flow to sheet flow that is evenly distributed across the entire Bioretention area.
- This requires a 2- to 4-inch elevation drop from a hard-edged surface into the Bioretention area.
- Manufactured Stormwater Devices (MTDs): An approved MTD may be used to provide pre-treatment.

### E.2.1.4 Construction Requirements

Do not construct Bioretention areas until all contributing drainage areas are stabilized as directed by the RCE. Do not use Bioretention areas as sediment control facilities for during construction sediment control. Do not operate heavy equipment within the perimeter of Bioretention areas during excavation, underdrain placement, backfilling, planting, or mulching.

Separate Bioretention areas from the water table to ensure groundwater does not enter the facility leading to groundwater contamination or Bioretention failure. Ensure a vertical distance of four (4) feet between the bottom of the Bioretention area and the seasonally high ground water table.

**Site Preparation**

Pre-treat stormwater runoff to reduce the incoming velocities, evenly spread the flow over the entire Bioretention area, and provides removal of coarse sediments. Because Bioretention areas are sensitive to fine sediments, do not install them on sites where the contributing area is not completely stabilized or is periodically being disturbed.

**Installation**

Bioretention areas work best when constructed off-line, capturing only the water quality volume. Divert excess runoff away from the Bioretention area or collect excess runoff with an overflow system. Install Bioretention areas around the natural topography to complement the surrounding landscape by fitting around sensitive areas, natural vegetation, roads, driveways, and parking lots. Bioretention areas have a minimum width of 10 feet and a minimum flow length of 40 feet to establish a strong healthy stand of vegetation.

## Excavation

Excavate the Bioretention area to the dimensions, side slopes, and elevations shown on the Plans. Excavate Bioretention areas to the required depth based on the plantings utilized. Ensure excavation minimizes the compaction of the bottom of the Bioretention area. Operate excavators and backhoes on the ground adjacent to the Bioretention area or use low ground-contact pressure equipment. Do not operate heavy equipment on the bottom of the Bioretention area. Remove excavated materials from the Bioretention area and dispose of them properly.

## Underdrain System

Prior to placing the underdrain system, alleviate compaction on the bottom of the Bioretention area by using a primary tilling operation such as a chisel plow, ripper, or subsoiler to a depth of 12 inches. Substitute methods must be approved by the RCE. Rototillers typically do not till deep enough to reduce the effects of compaction from heavy equipment.

Remove any ponded water from the bottom of the excavated area. Line the excavated area with a Class 2, Type C nonwoven geotextile fabric.

Place a layer of No. 57 Aggregate three (3) feet wide and minimum of three (3) inches deep on top of the nonwoven filter fabric. Place the pipe underdrains on top of the underlying aggregate layer. Lay the underdrain pipe at a minimum 0.5 percent longitudinal slope. The perforated underdrain drain pipe may be connected to a stormwater conveyance system or stabilized outlet. Cap the ends of underdrain pipes not terminating in an observation well.

Install observation wells/cleanouts of non-perforated vertically in the Bioretention area. Install observation wells and/or clean-out pipes at the ratio of one minimum per every 1,000 square feet of surface area as shown on the Plans. Connect the wells/cleanouts to the perforated underdrain with the appropriate manufactured connections as shown on the Plans. Extend the wells/cleanouts six (6) inches above the top elevation of the Bioretention area mulch layer and cap with a screw cap.

Place No. 57 Aggregate around the pipe underdrain system to a minimum depth of 8 inches. Place a Class 2, Type C nonwoven geotextile fabric between the boundary of the gravel and the filter media to prohibit the filter media from filtering down to the perforated pipe underdrain.

Place an outflow structure at the elevation of the maximum 9- to 12-inch ponding depth of the Bioretention area to carry excess runoff from the Bioretention area to a stormwater conveyance system or stabilized outlet.

## Internal Water Storage Zone (Denitrification Zone)

Create the Internal Water Storage Zone by adding a 90 degree angle (elbow) to the outlet of the underdrain system that is perpendicular (vertical) to the horizontal underdrain. The 90 degree elbow extends to a minimum height of 12 inches above the invert of the underdrain system. The pipe from the elbow will reconnect with the underdrain pipe upstream of the overflow spillway. Install a valve at the 90 degree elbow to allow drainage of the Internal Water Storage Zone. Install the 90 degree elbow and valve in the primary outlet structure or in an access well for a means of opening/closing the valve.

**Filter Media**

Install a permeable, non-woven geotextile filter fabric between the filter media and the on-site soils. Place and grade the filter media using low ground-contact pressure equipment or excavators and/or backhoes operating on the ground adjacent to the Bioretention area. Do not use heavy equipment within the perimeter of the Bioretention area before, during, or after the placement of the filter media. Place the filter media in vertical layers with a thickness of 12 to 18 inches. Compact the filter media by saturating the entire Bioretention area after each lift of filter media is placed until water flows from the underdrain system. Apply water for saturation by spraying or sprinkling. Perform saturation of each lift in the presence of the RCE. Do not use equipment to compact the filter media. Use an appropriate sediment control BMP to treat any sediment-laden water discharged from the underdrain during the settling process.

Test the installed filter media to determine the actual infiltration rate after placement. Ensure the infiltration rate is within the range of one (1) to six (6) inches per hour.

**Plantings**

Plant all Bioretention areas grasses, native grasses, perennials, shrubs, trees, and other plant materials specified to applicable landscaping standards.

Ensure all plant materials are kept moist during transport and on-site storage. Plant the root ball so one-eighth ($^1/_8$) of the ball is above final filter media surface. Ensure the diameter of the planting pit/hole is at least six (6) inches larger than the diameter of the planting ball. Set and maintain the plant straight during the entire planting process. Thoroughly water all plantings after installation.

Brace trees using 2-inch by 2-inch stakes only as necessary. Ensure stakes are equally spaced on the outside of the tree ball.

**Mulch**

Immediately mulch the entire Bioretention area to a uniform thickness of three (3) inches after all plantings are in place. Do not use mulch for Bioretention areas that utilize turf grass as the only vegetation material.

### E.2.1.5 Inspection and Maintenance

Regular inspection and maintenance is critical to the effective operation of Bioretention areas.

The surface of the ponding area may become clogged with fine sediments over time. Perform light core aeration or cultivate unvegetated areas as required to ensure adequate filtration. Other required maintenance includes but is not limited to:

- Perform pruning and weeding to maintain appearance periodically as needed.
- Replace or replenish mulch periodically as needed.
- Remove trash and debris periodically as needed.

**Table E.20: Bioretention Maintenance Requirements**

| Required Maintenance | Frequency |
|---|---|
| Pruning and weeding | As needed |
| Remove trash and debris | As needed |
| Inspect inflow points for clogging and remove any sediment | Semi-annual (every 6 months) |
| Repair eroded areas and re-seed or sod as necessary | Semi-annual (every 6 months) |
| Mulch void areas | Semi-annual (every 6 months) |
| Inspect trees and shrubs to evaluate their health | Semi-annual (every 6 months) |
| Remove and replace dead or severely diseased vegetation | Semi-annual (every 6 months) |
| Remove invasive vegetation | Semi-annual (every 6 months) |
| Nutrient and pesticide management | Annual, or as needed |
| Water vegetation, shrubs ,and trees | Semi-annual (every 6 months) |
| Remove mulch, reapply new layer | Annual |
| Test filter media for pH | Annual |
| Apply lime if pH < 5.2 | As needed |
| Add iron sulfate + sulfur if pH > 8.0 | As needed |
| Place fresh mulch over entire area | As needed |
| Replace pea gravel diaphragm | Every 2 to 3 years if needed |

## References

Clemson University Public Service Activities Carolina Clear, Rain Gardens, A Rain Garden Manual for South Carolina.

NCDENR Stormwater BMP Manual, Chapter 12 Bioretention, Chapter Revised 07-24-09 Prince George’s County, Maryland, Bioretention Design Specifications and Criteria, Section 2.0 - Siting and Design Criteria.

### E.2.2 Bio-Swales

A Bio-Swale is a shallow open-channel drainage way stabilized with turf grass to convey runoff and filter pollutants. Use Bio-Swales in medians and drainage conveyance swales or ditches as an enhancement to Grassed Channels and Swales. Bio-Swales are useful along roads that have driveway entrances crossing the swale. The maximum contributing drainage area for Bio-Swales is five (5) acres.

Bio-Swales are different from normal Grassed Channels and Swales in that they have structures implemented to enhance detention and stormwater pollutant removal. Bio-Swales are used for stormwater quality and have a limited ability to provide stormwater quantity control. Bio-Swales are vegetated channels that include a filter media that overlays an underdrain system. Bio-Swales are sized to allow the entire water quality storage volume to filter or infiltrate through the swale bottom. Because Bio-Swales are sensitive to fine sediments, do not install them on sites where the contributing area is not completely stabilized or is periodically being disturbed.

#### E.2.2.1 Design Requirements

To achieve 80% removal efficiency of the average annual post-development, Bio-Swales are designed to have a water quality volume equal to:

- One (1) inch of runoff from impervious areas located on the Project site, or
- 1.5 inches of runoff from built-upon portions of the Project within 1,000 feet of shellfish beds.

Design Bio-Swales to treat the water quality volume of runoff from the entire drainage basin. Calculate the surface area of the Bio-Swale by dividing the water quality volume by the ponding depth (18 inches).

Typical Bio-Swales have the following dimension:

- Minimum bottom width between two (2) and eight (8) feet
- Centerline slope of 1% - 2%
- 2:1 maximum side slopes (or flatter)
- Minimum filter media depth of two (2) feet

In order to allow for proper pollutant removal, design for the ponded runoff above the Bio-Swale surface to drain in a maximum of 12 hours. Design for runoff within the filter media to drain within 48 hours.

Design the underdrain system to safely pass the peak draw down flow rate of the filter media.

#### E.2.2.2 Materials

Bio-Swales consist of an underdrain system, filter media, plantings/vegetation, flow control structures, and a pre-treatment forebay.

Place flow control structures perpendicular to the Bio-Swale flow path to promote settling and infiltration.

**Table E.21: Bio-Swale Material Specifications**

| Material | Specification |
|---|---|
| No. 57 Aggregate | Use course aggregate No. 57 consisting of crushed slag or gravel |
| Pipe Underdrains | Use perforated pipe underdrains with a minimum diameter of 4 inches |
| Non-Woven Geotextile Fabric | Use Class 2 Type C non-woven geotextile fabric |
| Turf Reinforcement Matting (TRM) | Use a TRM that conforms with *Supplemental Technical Specification for RECPs(SC-M-815-9)*, or latest revision, for Turf Reinforcement Matting (TRM) description, materials, and construction requirements |

## Underdrain System

Use a minimum 4-inch diameter perforated PVC pipe in a 6-inch layer of No. 57 Aggregate gravel or equivalent filter material as the underdrain system. Place a Class 2 Type C permeable nonwoven geotextile filter fabric between the gravel and the overlaying permeable filter media.

## Filter Media

The filter media for Bio-Swales consists of a permeable layer that is a minimum of 2.0 feet deep. Provide a filter media with a minimum infiltration rate of 1.0 inch/hour and a maximum rate of 6.0 inches/hour. The filter media provides a medium for physical filtration for the stormwater runoff with enough organic matter content to support provide water and nutrients for plant life.

The USDA textural classification of the filter media is Loamy Sand or Sandy Loam. The filter media is furnished, and on-site soils are not acceptable.

Submit the source of the filter media and test results to the RCE prior to the start of construction of Bio-Swales. Do not add material to a stockpile of filter media once a stockpile has been sampled. Allow sufficient time for testing. Utilize a filter media from a certified source or laboratory to reduce mobilization time and construction delays.

Use a filter media that is uniform, free of stones, stumps, roots, or other similar objects larger than two inches excluding mulch. Do not mix or dump materials or substances within Bio-Swales that may be harmful to plant growth or prove a hindrance to the planting or maintenance operations.

Test the filter media to meet the following criteria:

**Table E.22: Filter Media Material Specifications**

| Item | Percent of Total Planting Mix by Weight | ASTM Sieve Size | Percent Passing by Weight |
|---|---|---|---|
| **Sand*** Clean, Washed, Well Graded, No Organic Material *Aggregate No. FA-10 ASTM C-33 Concrete Sand AASHTO M-6 AASHTO M-43, No. 9 or No. 10* | 80% Max | 3/8-inch | 100 |
| | | No. 4 | 95-100 |
| | | No. 8 | 80-100 |
| | | No. 16 | 50-85 |
| | | No. 30 | 25-60 |
| | | No. 50 | 10-30 |
| | | No. 100 | 2-10 |
| | | No. 200 | 0-3 |
| **Screened Topsoil** *Loamy Sand or Sandy Loam ASTM D5268 (imported or manufactured topsoil) Max 5% clay content* | 15% Max | 2-inch | 100 |
| | | 1-inch | 95- 100 |
| | | No. 4 | 75-100 |
| | | No. 10 | 60-100 |
| | | No. 200 | 10-50 |
| | | 0.002-mm | 0-5 |
| Organic Matter in the form of Compost, Leaf Compost, Peat Moss or Pinebark Nursery Mix** | 5% Min | 3/8-inch | 85-100 |
| | | No. 8 | 50-80 |
| | | No. 30 | 0-40 |

***Do not use lime stone screenings.***
***** Potting grade pine bark with no particles larger than ½ inches.***

## Forebay

Provide pre-treatment of runoff to Bio-Swales with a forebay. Forebays are typically provided by constructing a flow control structure at the inlet to the Bio-Swale. Protect forebay inlets to reduce erosive forces of the runoff. The preferable protective material is a Turf Reinforcement Mat (TRM).

## Outlet Structures

Discharge water from the underdrain system of Bio-Swales to a storm drainage system on-site or discharge to a stable protected outlet point.

## Flow Control Structures

Place flow control structures perpendicular to the Bio-Swale flow path to promote settling and infiltration. For maximum performance, Bio-Swales are recommended to be off-line structures. If a Bio-Swale is designed to be an online structure, the flow control structures must be able to safely pass runoff for the 10-year, 24-hour storm event.

## Plantings

Use plantings that conform to the standards of the current edition of *American Standard for Nursery Stock* as approved by the American Standards Institute, Inc.

Use plant materials that have normal, well-developed stems or branches and a vigorous root system. Only use plantings that are healthy and free from physical defects, plant diseases, and insect pests.

Use plant species that are tolerant to wide fluctuations in soil moisture content. Use plantings capable of tolerating saturated soil conditions for the length of time anticipated for the water quality volume, as well as anticipated runoff constituents.

Use turfgrass species that have a thick dense cover, are slow growing, are applicable to the expected moisture conditions (dry or wet), do not require frequent mowing, and have low nutrient requirements. Plant all permanent turf type grasses according to SCDOT *Supplemental Technical Specification for Seeding SC-M-810-2* or latest revision.

The preferred method of establishing turf grass is sodding. Use temporary erosion control blankets to provide temporary cover when establishing turf grass by seeding.

### E.2.2.3 Construction Requirements

**Site Preparation**

Do not install Bio-Swales on sites where the contributing area is not completely stabilized or is periodically being disturbed.

Separate Bio-Swales from the water table to ensure groundwater does not enter the facility leading to groundwater contamination Bio-Swale failure. Ensure a vertical distance of two (2) feet between the bottom of Bio-Swales and the seasonally high groundwater table.

**Excavation**

Ensure excavation minimizes the compaction of the bottom of Bio-Swales. Operate excavators and backhoes on the ground adjacent to Bio-Swales or use low ground-contact pressure equipment. Do not operate heavy equipment on the bottom of Bio-Swales.

**Underdrain System**

Prior to placing the underdrain system, alleviated compaction on the bottom of the Bio-Swale by using a primary tilling operation such as a chisel plow, ripper, or subsoiler to a depth of 12 inches. Substitute methods must be approved by the RCE. Rototillers typically do not till deep enough to reduce the effects of compaction from heavy equipment.

Remove any ponded water from the bottom of the excavated area. Line the excavated area with a Class 2, Type C nonwoven geotextile fabric.

Place a layer of No. 57 Aggregate a minimum of two (2) inches deep on top of the nonwoven filter fabric. Place the pipe underdrains on top of the underlying aggregate layer. Lay the underdrain pipe at a minimum 0.5 percent longitudinal slope. The perforated underdrain drain pipe may be connected to a stormwater conveyance system or stabilized outlet.

Place No. 57 Aggregate around the pipe underdrain system to a minimum depth of six (6) inches. Place a Class 2, Type C nonwoven geotextile fabric between the boundary of the gravel and the filter media to prohibit the filter media from filtering down to the perforated pipe underdrain.

**Filter Media**

Place and grade the filter media using low ground-contact pressure equipment or excavators and/or backhoes operating on the ground adjacent to the Bio-Swale. Do not use heavy equipment within the perimeter of the Bio-Swale before, during, or after the placement of the filter media. Place the filter media in vertical layers with a thickness of 12 inches. Compact the filter media by saturating the entire Bio-Swale after each lift of filter media is placed until water flows from the underdrain system. Apply water for saturation by spraying or sprinkling. Perform saturation of each lift in the presence of the RCE. Do not use equipment to compact the filter media. Use an appropriate sediment control BMP to treat any sediment-laden water discharged from the underdrain during the settling process.

Test the installed filter media to determine the actual infiltration rate after placement. Ensure the infiltration rate is within the range of one (1) to sis (6) inches per hour.

**Bio-Swale Surface**

Install Bio-Swales with a bottom width ranging between two (2) and eight (8) feet where applicable to ensure an adequate filtration area. Where the site allows, increase the filtration area by using wider channels, giving consideration to prevent uncontrolled sub-channel formation. Install Bio-Swale surface side slopes that are 4H:1V for ease of maintenance and for side inflow to remain as sheet flow. The maximum Bio-Swale surface side slopes are 2H:1V.

Install Bio-Swales with a minimal surface channel slope ranging from one to two percent, forcing a slow and shallow flow. This aspect of the Bio-Swale allows particulates to settle out of the runoff and limits erosion. Place flow control structures perpendicular to the Bio-Swale flow path to promote settling and infiltration. Space flow controls structures a minimum of 50 feet apart and install energy dissipation techniques on the downstream side of these structures.

Flow can enter the Bio-Swale through a pre-treatment forebay or it may enter along the sides of the swale as sheet flow produced by level spreader trenches along the top of the bank.

**Plantings**

Plant all Bio-Swale grasses, native grasses, perennials, shrubs, and other plant materials specified to applicable landscaping standards. Plant all permanent turf type grasses according to SCDOT *Supplemental Technical Specification for Seeding SC-M-810-2* or latest revision.

### E.2.2.4 Inspection and Maintenance

Regular inspection and maintenance is critical to the effective operation of Bio-Swales. Typical maintenance responsibilities include:

- Keep a record of the average de-watering time of the Bio-Swale to determine if maintenance is required.

- Perform light core aeration as required to ensure adequate filtration when the surface of the filter bed becomes clogged with fine sediments over.
- Perform mowing to maintain storage volume and to maintain appearance periodically as needed.
- Remove trash and debris periodically as needed.

**Table E.23: Bio-Swale Maintenance Requirements**

| Required Maintenance | Frequency |
|---|---|
| Mow grass to maintain design height and remove clippings | As needed (frequent/seasonally) |
| Nutrient and pesticide management | Annual, or as needed |
| Inspect side slopes for erosion and repair | Annual, or as needed |
| Inspect channel bottom for erosion and repair | Annual, or as needed |
| Remove trash and debris accumulated in forebay | Annual |
| Inspect vegetation and plant an alternative grass species if original cover is not established | Annual (semi-annually first year) |
| Inspect for clogging and correct the problem | Annual |
| Rototill or cultivate the surface of the bed when the Bio-Swale does not draw down in 48 hours | As needed |
| Remove sediment build-up within the bottom of the Bio-Swale | As needed, after 25% of the original design volume has filled. |

### E.2.3 Natural Infiltration

#### E.2.3.1 Description

Natural infiltration is a method in which an undisturbed land area covered with natural vegetation accepts runoff from and infiltrates the runoff into the soil. Natural infiltration areas should only be used where the soils are suitable for infiltration. The area should be in a forested condition with the land surface covered by leaves, pine needles, and other forest floor organic materials.

#### E.2.3.2 Design Requirements

To achieve 80% removal efficiency of the average annual post-development natural infiltration is designed to have a water quality volume equal to:

- One (1) inch of runoff from impervious areas located on the Project site, or
- 1.5 inches of runoff from built-upon portions of the Project within 1,000 feet of shellfish beds.

The size of a natural infiltration area can be calculated using the following equation:

$$A = \frac{K * T * I}{[(cd) - K]}$$

Where:

***A*** = Natural infiltration area required (acres)

***K*** = Runoff volume to infiltrate (inches)

***T*** = Total site area or total drainage area (acres)

***I*** = Built upon area ratio (Built upon area / T)

***c*** = Effective water capacity (in/in), determined from site-specific soil samples

***d*** = Depth of soil A horizon (inches), determined from site-specific soil samples

The runoff from the areas to be treated by natural infiltration shall enter the infiltration area as sheet flow with a non-erosive velocity. A portion of the areas to be treated shall be stabilized and vegetated a minimum of 20 feet in length prior to entering the infiltration area to reduce the amount of course particles entering the infiltration area.

Natural infiltration areas have the following characteristics:

- Appropriate soils that have a minimum infiltration rate of 0.3 inches per hour, low erosion potential, and good drainage (not in a wetland or floodplain).
- Mature forest cover (if the natural infiltration area (A) is not located in a mature forest, then the area shall be double of that calculated by the equation above).
- Slopes less than 10 percent.
- The natural infiltration area shall remain permanently undisturbed.
- The limitations of natural infiltration areas include:
    - Not suitable for soils that have greater than 30 percent clay content or greater than 40 percent clay and silt content.
    - Not suitable in areas with high water tables or shallow depth to highly impervious strata such as bedrock or clay layers.
    - High sediment loading or lack of maintenance clogs the surface layer therefore inhibiting any water infiltration into the soil.

### E.2.4 Stormwater MTDs

Design and select Stormwater Manufactured Treatment Devices (MTDs) to treat at a minimum the peak flow rate of the stormwater runoff from the 1.8-inch, 1-year, 24-hour storm event for the entire drainage area to the BMP. Refer to *SCDOT Supplemental Technical Specification for Manufactured Stormwater Treatment Devices (MTDs) SC-M-815-13* or latest revision for specific design requirements.