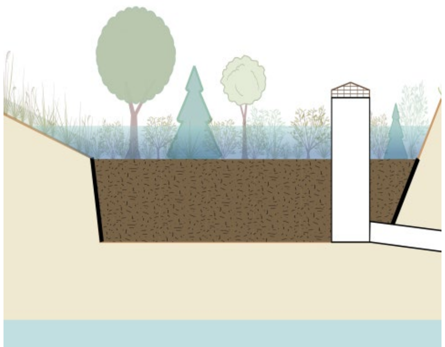
10.1 Bioretention Systems (Large-Scale)



Bioretention systems are stormwater management facilities used to address the stormwater quality and quantity impacts of land development. The system consists of a soil bed planted with vegetation; it can be underdrained, or stormwater runoff can infiltrate into the subsoil. Pollutants are treated through the processes of settling and uptake and filtration by the vegetation. Pollutants are also treated within the soil bed through infiltration. The total suspended solids (TSS) removal rate is 80 - 90%; this rate will depend on the depth of the soil bed and the type of vegetation selected.

N.J.A.C. 7:8 Stormwater Management Rules – Applicable Design and Performance Standards		
	Green Infrastructure	Yes
	Stormwater Runoff Quantity	Yes, when designed as an on-line system
GR	Groundwater Recharge	Only with a waiver or variance from N.J.A.C. 7:8-5.3, for systems designed to infiltrate into the subsoil
%	Stormwater Runoff Quality	Only with a waiver or variance from N.J.A.C. 7:8-5.3, 80 - 90% TSS Removal, Depending on Vegetation Selection and Depth of Soil Bed

Stormwater Runoff Quality Mechanisms and Corresponding Criteria	
Settling	
Storage Volume	Entire Water Quality Design Storm Volume
Vegetative Uptake and Filtration	
Minimum Density of Vegetation	85%
Appropriate Species Selection	See *Chapter 7: Landscaping*
Depth of Soil Bed	1.5 - 2 feet, See *Chapter 9.7: Small-scale Bioretention Systems*
Infiltration	
Maximum Design Storm Drain Time	72 hours, Using Slowest Design Permeability Rate
Permeability Rate Factor of Safety	2
Minimum Subsoil Design Permeability Rate	0.5 inches/hour
Soil Testing Consistent with *Chapter 12: Soil Testing Criteria*	Required

Introduction

Like the small-scale bioretention systems found in *Chapter 9.7*, bioretention systems are vegetated stormwater management facilities that are used to remove a wide range of pollutants from land development sites; these pollutants include suspended solids, nutrients, metals, hydrocarbons and bacteria. Stormwater runoff entering the system is filtered through the soil bed before discharging downstream through an underdrain or infiltrating into the subsoil. Vegetation in the soil bed provides uptake of pollutants and runoff, and the root system helps maintain the infiltration rate in the soil bed. Bioretention systems may also be used to reduce peak runoff rates when designed as a multi-stage, multi-function facility. However, there is no contributory drainage area maximum applicable to the bioretention systems discussed in this chapter.

In bioretention systems designed to infiltrate into the subsoil, the rate of infiltration is affected by the permeability of the subsoil, the distance separating the basin bottom from the seasonal high water table (SHWT) and the area of the basin bottom. While loss of subsoil permeability through soil compaction is a concern, transport of dissolved pollutants by highly permeable subsoils is of equal concern. Therefore, due to the potential for groundwater contamination, the use of bioretention systems designed to infiltrate into the subsoil is prohibited in areas where high pollutant or sediment loading is anticipated. For more information regarding stormwater runoff that may not be infiltrated, refer to N.J.A.C. 7:8-5.4(b)3. However, this prohibition is limited only to areas onsite where this type of loading is expected; runoff from areas onsite that are grade-separated may be collected in bioretention systems designed to infiltrate into the subsoil provided that the location of the bioretention system is not inconsistent with an NJDEP-approved remedial action work plan or landfill closure plan.

Bioretention systems designed to infiltrate into the subsoil may not be used where their installation would create a significant risk of adverse hydraulic impacts. These impacts may include exacerbating a naturally or seasonally high water table so as to cause surficial ponding, flooding of basements, or interference with the proper operation of a subsurface sewage disposal system or other subsurface structure, or where their construction will compact the subsoil. Hydraulic impacts on the groundwater table must be assessed. For more information on groundwater mounding analysis, refer to *Chapter 13: Groundwater Table Hydraulic Impact Assessments for Infiltration BMPs*

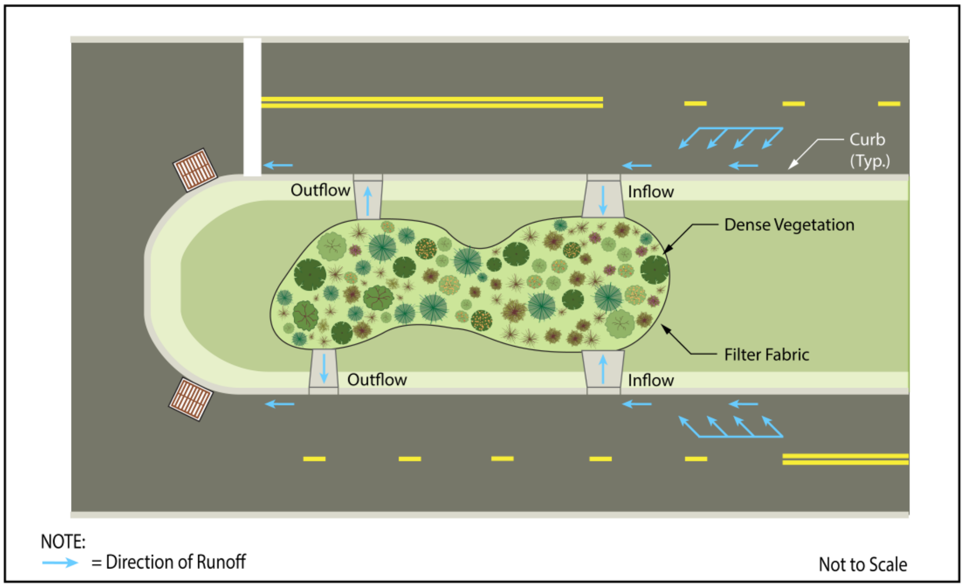
Bioretention systems vary in size and shape. They may be designed in the shape of a traditional basin, or they may be designed in the shape of a swale, making them particularly suited to placement along roadways. Bioretention systems may also be designed with either a flat- or sloped-bottom. This flexibility in design allows bioretention systems to be used in a variety of locations, including lawns, median strips, parking lot islands, vacant lots and some easements. However, they are most effective when they are sited as close as possible to the source of runoff.

Bioretention systems can only be used to satisfy the standards for stormwater runoff quantity, unless a waiver from the green infrastructure requirements of N.J.A.C. 7:8-5.3 is obtained.

A bioretention system must have a maintenance plan and must be reflected in a deed notice recorded in the county clerk's office to prevent alteration or removal.

The following illustration shows a street median bioretention system. Stormwater runoff is directed into the system through depressed sections of curb; excess runoff flows back to the street where it discharges into the stormwater collection system.

Median Bioretention System – Plan View



Applications

Pursuant to N.J.A.C. 7:8-5.2(a)(2), the minimum design and performance standards for groundwater recharge, stormwater runoff quality and stormwater runoff quantity at N.J.A.C. 7:8- 5.4, 5.5 and 5.6 shall be met by incorporating green infrastructure in accordance with N.J.A.C. 7:8-5.3. Pursuant to N.J.A.C. 7:8-5.3(c), large-scale green infrastructure BMPs - i.e., those that exceed the contributory drainage area limits at N.J.A.C. 7:8-5.3(b) - may only be used to satisfy the stormwater runoff quantity standards.

Bioretention systems may be designed to convey storm events larger than the Water Quality Design Storm (WQDS); however, regardless of the design storm chosen, all bioretention systems must be designed for stability and in accordance with the *Standards for Soil Erosion and Sediment Control in New Jersey.*

Only if a waiver or variance from the green infrastructure requirements of N.J.A.C. 7:8-5.3 is obtained may bioretention systems designed to infiltrate into the subsoil that exceed the contributory drainage area limit of 5.3(b) be used to meet the groundwater recharge requirements. For more information on computing groundwater recharge, see *Chapter 6: Groundwater Recharge.*

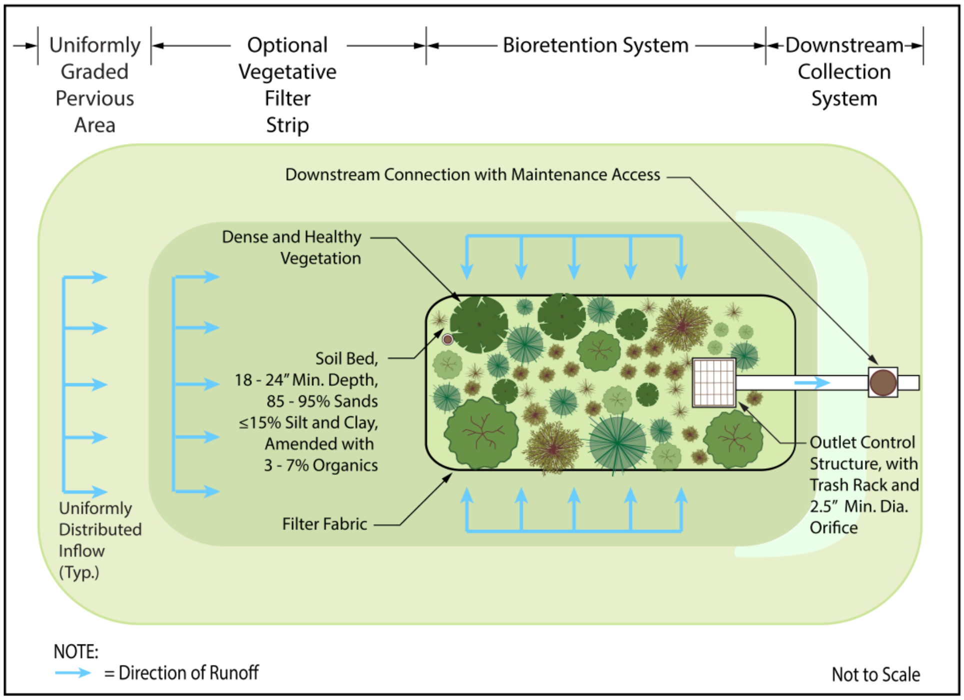
Only if a waiver or variance from the green infrastructure requirements of N.J.A.C. 7:8-5.3 is obtained may bioretention systems that exceed the contributory drainage area limit of 5.3(b) be used to meet the stormwater runoff quality requirement.

Design Criteria

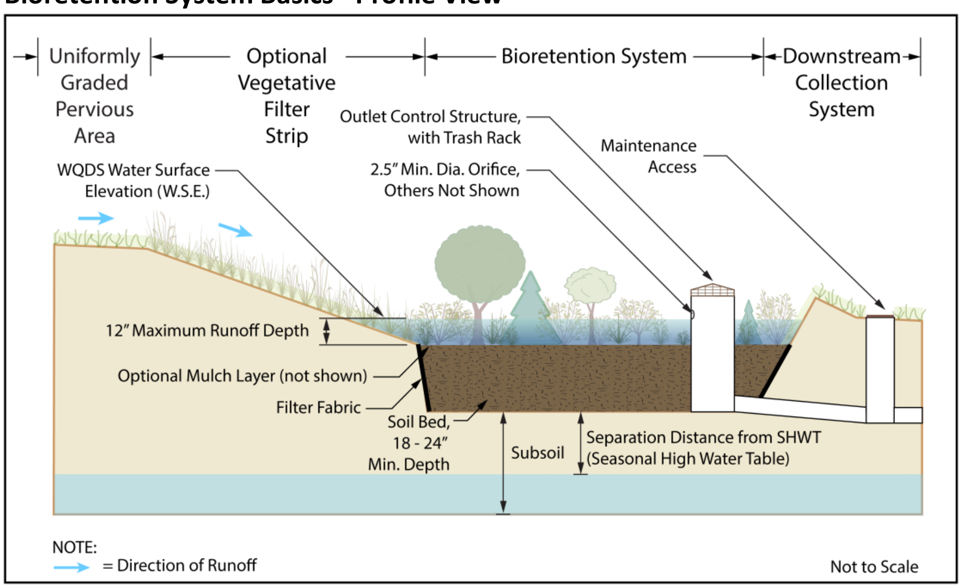
Basic Requirements

Although the subsurface components differ, underdrained bioretention systems and those designed to infiltrate have common surface elements, which are shown in the figures below and discussed on the following pages. In the following illustrations, a vegetative filter strip provides pretreatment and a downstream collection system receives runoff that does not infiltrate.

Bioretention System Basics - Plan View



Bioretention System Basics - Profile View



The following design criteria apply to both types of bioretention systems. Additional design criteria are found, beginning on Page 11, for a system with an underdrain and Page 13, for a system designed to infiltrate into the subsoil.

Inflow

- All inflow must be stable and non-erosive and designed in accordance with the *Standards for Soil Erosion and Sediment Control in New Jersey.*
- All inflow must be evenly distributed across the surface of the bioretention system to ensure all vegetation receives sufficient runoff during small rain events.
- For systems with multiple bioretention systems, inflow has to be distributed proportionally based on the surface area of each unit, especially when using bioretention systems in series, to ensure that each unit receives sufficient flow to support vegetation.

Storage Volume

- The system must have sufficient storage volume to contain the Water Quality Design Storm (WQDS) stormwater runoff volume without overflow.
- Bioretention systems may be constructed as either off-line or on-line systems. In off-line systems, most, or all, of the runoff from storms larger than the WQDS bypass the bioretention basin through an upstream diversion; this reduces the size of the required basin storage volume, the system's long-term pollutant loading and associated maintenance. On-line systems receive runoff from all storm events; they provide treatment for the WQDS, and they convey the runoff from larger storms through an overflow. These on-line systems store and attenuate the larger storm events and provide stormwater runoff quantity control; in such systems, the invert of the lowest quantity control outlet is set at the water surface elevation of the WQDS.
- Bioretention systems must contain only the WQDS or smaller storm events below the first outlet control structure. See Page 11 for details pertaining to an underdrained system and Page 13 for a system designed to infiltrate.
- For the WQDS, the maximum depth of runoff is 12 inches in a flat-bottom bioretention system, when designed in accordance with the other design criteria found in this chapter.
- Bioretention systems must not include exfiltration in the routing calculations.
- Bioretention systems are intended to be free of standing water between storm events; therefore, the drain time for standing water present on the surface of soil bed, in the overflow structure, or in the underdrain pipe system must not exceed 72 hours after any rain event. Storage times in excess of 72 hours may render a bioretention system ineffective and may result in anaerobic conditions, odor, and both water quality and mosquito breeding issues.

Geometry

- The maximum side slope ratio for earthen embankments is 3:1.

- The system must have a sufficient surface area to prevent stormwater runoff depths in excess of the maximum depth requirement as well as ensure that stormwater is able to spread out over the entire soil bed, i.e., the system footprint.

Vegetation

- Bioretention systems are designed with varying wetness zones; therefore, vegetation must be selected and placed based on specific water requirements and tolerances.

- The distribution of trees and shrubs must be based on specific site conditions. On average, the number of stems required per acre is 1,000, with trees and shrubs spaced 12 feet and 8 feet apart, respectively.

- For more information on appropriate vegetation for bioretention systems, see *Chapter 7: Landscaping*.

Soil Bed

- The soil bed must be a minimum of 18 – 24 inches in depth, in accordance with *Chapter 9.7: Small-scale Bioretention Systems*.

- The soil bed material must consist of the following mix, by volume: 85 to 95% sand, with no more than 25% of the sand as fine or very fine sands; no more than 15% silt and clay with 2% to 5% clay content. The entire mix must then be amended with 3 to 7% organics, by weight.

- The soil bed material shall be free of contaminants.

- Pre-mixed soil must be certified to be consistent with the requirement above by either the vendor or by a professional engineer licensed by the State of New Jersey. The content of any soil mixed on-site must be certified by a professional engineer licensed by the State of New Jersey; in addition, the engineer must be present while the soil is mixed.

- The pH of the soil bed material is recommended to range from 5.5 to 6.5.

- The soil bed material must be placed in lifts not to exceed 8 inches. Additional materials may be necessary to account for settling over time.

Safety

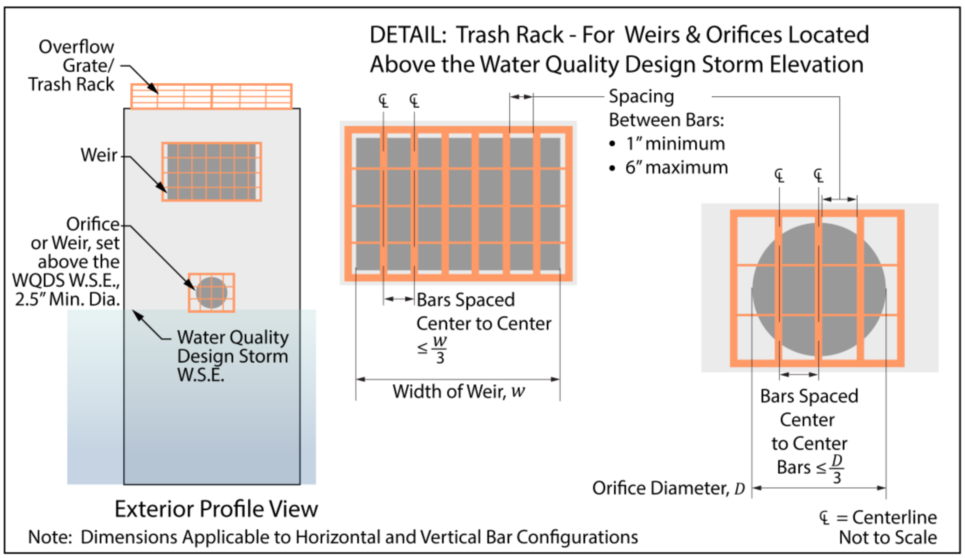
- All bioretention basins must be designed to safely convey overflows to downstream drainage systems. The design of any overflow structure must be sufficient to provide safe, stable discharge of stormwater in the event of an overflow. Safe and stable discharge minimizes the possibility of adverse impacts, including erosion and flooding in down-gradient areas. Therefore, discharge in the event of an overflow must be consistent with the *Standards for Off-Site Stability* found in the *Standards for Soil Erosion and Sediment Control in New Jersey*.

- Bioretention basins that are classified as dams under the NJDEP Dam Safety Standards at N.J.A.C. 7:20 must meet the overflow requirements under these regulations. Overflow capacity can be provided by a hydraulic structure, such as a weir or orifice, or a surface feature, such as a swale or open channel.

Outlet Structure

- For systems designed with an outlet structure, trash racks must be installed at the intake to the outlet structure. They must meet the following criteria illustrated below:

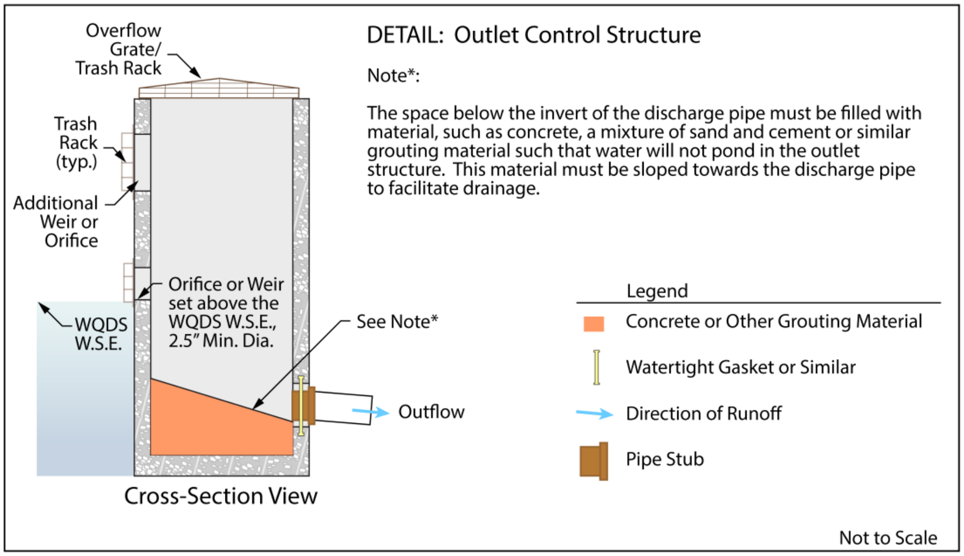
  - □ Parallel bars with 1-inch spacing between the bars up to the elevation of the WQDS;
  - □ Parallel bars higher than the elevation of the WQDS must be spaced no greater than one-third the width of the diameter of the orifice or one-third the width of the weir, with minimum spacing between bars of 1 inch and a maximum spacing between the bars of six inches;
  - □ The trash rack must be designed so as not to adversely affect the hydraulic performance of the outlet pipe or structure;
  - □ Constructed of rigid, durable and corrosion-resistant material; and
  - □ Designed to withstand a perpendicular live loading of 300 lbs/sf.



- An overflow grate is designed to prevent obstruction of the overflow structure. If an outlet structure has an overflow grate, the grate must comply with the following requirements:

  - □ The overflow grate must be secured to the outlet structure but removable for emergencies and maintenance;
  - □ The overflow grate spacing must be no greater than 2 inches across the smallest dimension; and
  - □ The overflow grate must be constructed of rigid, durable, and corrosion resistant material and designed to withstand a perpendicular live loading of 300 lbs./sf.

- The space below the invert of the discharge pipe must be filled with material, such as concrete, a mixture of sand and cement, or similar grouting material, such that water will not pond in the outlet structure. This material must be sloped towards the discharge pipe to facilitate drainage, as shown on the next page.



- The minimum diameter of any overflow orifice is 2.5 inches.
- Blind connections to down-gradient facilities are prohibited. Any connection to down-gradient stormwater management facilities must include access points such as inspections ports and manholes, for visual inspection and maintenance, as appropriate, to prevent blockage of flow and ensure operation as intended. All entrance points must adhere to all Federal, State, County and municipal safety standards such as those for confined space entry.
- In instances where the lowest invert in the outlet or overflow structure is below the flood hazard area design flood or tide elevation in a down-gradient waterway or stormwater collection system, the effects of tailwater on the hydraulic design of the underdrain and overflow systems, as well as any stormwater quantity control outlets, must be analyzed. Two methods to analyze tailwater are:
  - A simple method entails inputting flood elevations for the 2-, 10-, and 100-year events as static tailwater during routing calculations for each storm event. These flood elevations are either obtained from a Department flood hazard area delineation or a FEMA flood hazard area delineation that includes the 100-year flood elevation or derived using a combination of NRCS hydrologic methodology and a standard step backwater analysis or level pool routing, where applicable. In areas where the 2-year or 10-year flood elevation does not exist in a FEMA or Department delineation, it may be interpolated or extrapolated from the existing data. If this method demonstrates that the requirements of the regulations are met with the tailwater effect, then the design is acceptable. If the analysis shows that the requirements are not met with the tailwater effects, the detailed method below can be used or the BMP must be redesigned.
  - A detailed method entails the calculation of hydrographs for the watercourse during the 2, 10, and 100-year events using NRCS hydrologic methodology. These hydrographs are input into a computer program to calculate rating curves for each event. Those rating curves are then input as a dynamic tailwater during the routing calculations for each of the 2, 10, and 100-year events. This method may be used in all circumstances; however, it may require more advanced computer programs. If this method demonstrates that the requirements of the regulations are met with the tailwater effect, then the design is acceptable. If the analysis shows that the requirements are not met with the tailwater effects, the BMP must be redesigned.

- Under no circumstances may a drain-down valve or other dewatering measure be included in the design of the bioretention system, even if it was intended to remain open or unused during normal operation.

Construction Requirements

- During clearing and grading of the site, measures must be taken to eliminate soil compaction at the location of a proposed bioretention system.

- The location of the proposed bioretention system must also be cordoned off during construction to prevent compaction of the subsoil by construction equipment or stockpiles.

- Excavation and construction of a bioretention system must be performed with equipment placed outside the limits of the basin.

- The location of the proposed bioretention system should not be used to provide sediment control during construction; however, when unavoidable, the bottom of the sediment control basin should be at least 2 feet above the final design elevation of the bottom of the soil bed in the bioretention basin.

- The excavation to the final design elevation of the bioretention system bottom may only occur after all construction within its drainage area is completed and the drainage area is stabilized. If construction of the bioretention system cannot be delayed, berms must be placed around the perimeter of the system during all phases of construction to divert all flows away from the bioretention system. The berms may not be removed until all construction within the drainage area is completed and the area is stabilized.

- The contributing drainage area must be completely stabilized prior to bioretention system use.

- Post-construction testing must be performed on the as-built bioretention system in accordance with the Construction and Post-Construction Oversight and Soil Permeability Testing section in *Chapter 12: Soil Testing Criteria* of this manual. To ensure that the as-built system functions as designed, post-construction testing must include a determination of the permeability rates of the soil bed and the hydraulic capacity of the underdrain, in underdrained systems, or the permeability of the subsoil, in infiltration systems. Where as-built testing results in longer drain times than designed, corrective action must be taken. The drain time is defined as the time it takes to fully infiltrate the maximum design storm runoff volume through the most hydraulically restrictive layer.

Access Requirements

- An access roadway must be included in the design to facilitate monitoring and maintenance. If the access roadway is constructed of impervious material, take note that it may be subject to the stormwater runoff quality, quantity, and/or groundwater recharge requirements at N.J.A.C. 7:8-5.4, 5.5 and 5.6.

- Additional steps may be necessary to eliminate vehicular intrusion into the basin footprint, such as from all-terrain vehicles and utility trucks.

Types of Bioretention Systems

Bioretention systems can be divided into two subtypes based on how runoff is discharged from the system. There are two types of bioretention systems:

1. Bioretention Systems with Underdrains
2. Bioretention Systems Designed to Infiltrate into the Subsoil

Individual Types of Bioretention Systems

The following section provides detailed design criteria for each type of bioretention system; the illustrations include pretreatment provided by a vegetative filter strip. The illustrations show possible configurations and flow paths and are not intended to limit the design. An additional illustration providing a side by side comparison of the two types of bioretention systems is found on Page 14.

Bioretention Systems with Underdrains

- Take note that this type of system cannot be used to infiltrate stormwater runoff into the subsoil nor provide groundwater recharge.

- Filter fabric is required along both the sides and the bottom of the basin to prevent the migration of fine particles from the surrounding soil, if an earthen embankment is used.

- The underdrain consists of three components – the sand layer, the gravel layer and the network of pipes that collect stormwater runoff and transport it to the outflow section of the system.
  - The sand layer, which acts as a transition between the soil bed and the subsequent layers, must be at least 6 inches in depth and must consist of clean, medium-aggregate concrete sand (AASHTO M-6/ASTM C-33). To ensure proper system operation, the permeability rate of the sand layer must be at least twice the design permeability rate of the soil bed.
  - The gravel layer must have sufficient depth to provide at least 3 inches of gravel above and below the pipe network and must consist of 0.5 to 1.5 inch clean, broken stone or pea gravel (AASHTO M-43). To ensure proper system operation, the permeability rate of the gravel layer must be at least twice the design permeability rate of the sand layer.
  - Within the gravel layer, the network of pipes, excluding any manifolds and inspection ports, must be perforated. All remaining pipes must be non-perforated. All joints must be secure and watertight. To ensure proper system operation, the network of pipes must have a conveyance rate at least twice as fast as the design flow rate through the sand layer.
  - Inspection ports must be located at the upstream and downstream ends of the perforated section of the network of pipes and extend above the surface of the soil bed. The inspection port exterior must be covered in such a way as to prevent the migration of material into the structure. The depth of runoff generated by the maximum design storm must be marked on all inspection ports and those levels included in the design report and maintenance plan.
  - The overflow pipe should not be connected to the perforated portion of the underdrain pipe. However, the overflow pipe and the underdrain pipe may discharge to the same conveyance system down-gradient of the bioretention system, provided that the overflow discharge will

not back up to the perforated portion of the underdrain pipe nor affect the drainage capacity of the underdrain pipe system.
- Flexible corrugated perforated plastic drain pipe should not be used as underdrain pipe.

- The volume of stormwater runoff generated by the WQDS is the maximum storm to be used to calculate the area, also known as the footprint, of the bottom of the bioretention system designed with an underdrain, in conjunction with the appropriate maximum depth discussed on Page 5. The invert of the lowest discharge orifice must be set at an elevation that allows the entire volume of stormwater runoff generated by the WQDS to be filtered through the soil bed, followed by the sand layer, and into the underdrain pipe network.

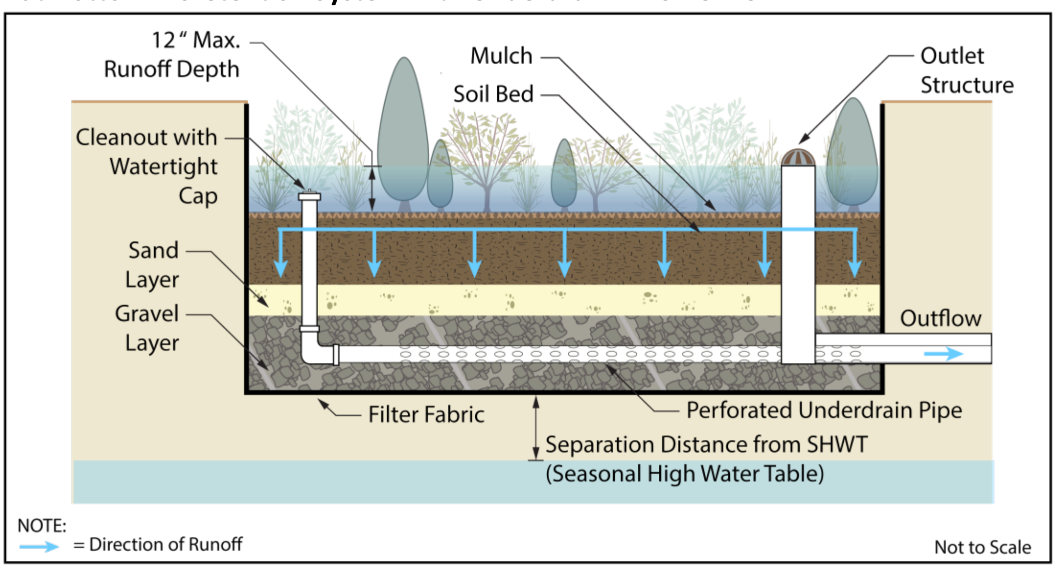
- The capacity of the underdrain must be sufficient to allow the system to drain within 72 hours.

- The seasonal high water table (SHWT) must be at least 1 foot below the bottom of the gravel layer.

- All points of access must also be covered in such a way as to prevent sediment or other material from entering the system and to prevent the accumulation of standing water, which could lead to mosquito breeding.

The graphic below shows a bioretention system designed with an underdrain. Although not labeled in the graphic, the perforated underdrain pipe must have a 3 inch minimum thickness of gravel cover above and below the underdrain pipe. In this illustration, the outlet control structure also serves as the down-gradient inspection port. Additional maintenance access is provided at the connection to the downstream stormwater collection system.

Flat-Bottom Bioretention System with Underdrain - Profile View



Bioretention Systems Designed to Infiltrate into the Subsoil

The following design standards apply to bioretention systems designed to infiltrate:

- The bottom of a bioretention system must be as level as possible in order to allow stormwater runoff to uniformly infiltrate into the subsoil.

- The SHWT or bedrock must be at least 2 feet below the bottom of the soil bed.

- The following permeability requirements apply:

    - The permeability of the subsoil must be sufficient to allow the system to drain within 72 hours; however, if the bioretention system is installed in an area subject to pedestrian traffic, the drain time should be reduced to 24 hours.
    - Soil tests are required at the exact location of the proposed basin in order to confirm its ability to function as designed. Take note that permits may be required for soil testing in regulated areas, such as areas regulated under the Flood Hazard Area Control Act Rules (N.J.A.C. 7:13), the Freshwater Wetlands Protection Act Rules (N.J.A.C. 7:7A), the Coastal Zone Management Rules (N.J.A.C. 7:7), and the Highlands Water Protection and Planning Rules (N.J.A.C. 7:38).
    - The testing of all permeability rates must be consistent with *Chapter 12* in this manual, including the required information to be included in the soil logs, which can be found in section *3.b Soil Logs*. In accordance with N.J.A.C. 7:9A-6.2(j)1, *Standards for Individual Subsurface Sewage Disposal Systems*, the slowest tested permeability must be used for design purposes.
    - Since the actual permeability rate may vary from soil testing results and may decrease over time, a factor of safety of 2 must be applied to the slowest tested permeability rate to determine the design permeability rate. The design permeability rate would then be used to compute the system's drain time for the maximum design volume. The drain time is defined as the time it takes to fully infiltrate the maximum design storm runoff volume through the most hydraulically restrictive layer.
    - The maximum design permeability rate is 10 inches/hour for any tested permeability rate of 20 inches/hour or more.
    - The minimum design permeability rate of the subsoil is 0.5 inches/hour, which equates to a minimum tested permeability rate of 1.0 inch/hour.

- Filter fabric is required along the sides of the soil bed to prevent the migration of fine particles from the surrounding soil. However, unlike systems with underdrains, filter fabric may not be used along the bottom of the soil bed because it may result in a loss of permeability.

- As with any infiltration BMP, groundwater mounding impacts must be assessed, as required by N.J.A.C. 7:8-5.2(h). This includes an analysis of the reduction in permeability rate when groundwater mounding is present.

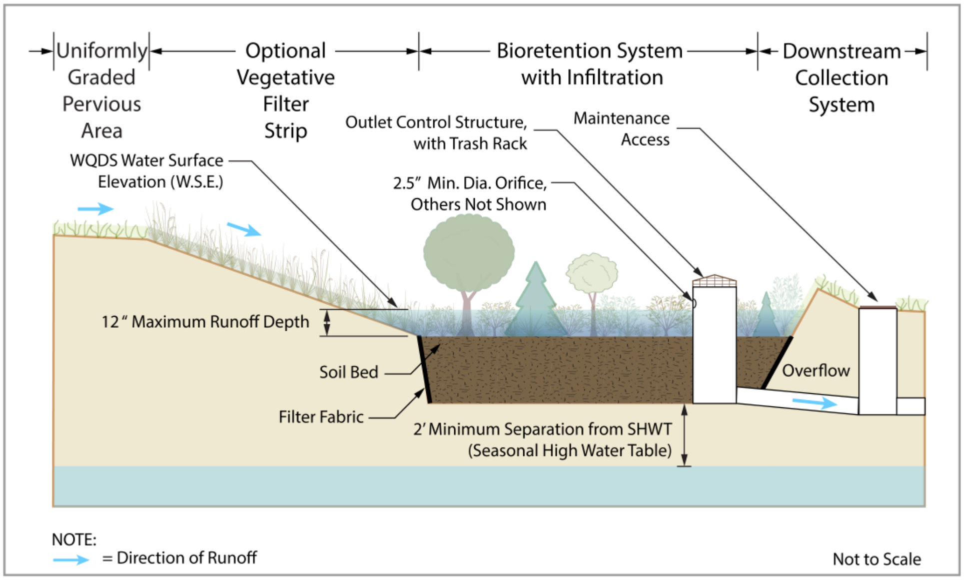
    - Additional trials may be required, including using a reduced recharge rate in accordance with the method published in *Chapter 5*, should the calculations demonstrate an adverse impact is produced. Refer to the information labeled "*Steps to Follow When an Adverse Impact is Encountered*" found on Page 53 of *Chapter 5*.

- □ Where the mounding analysis identifies adverse impacts, the bioretention system must be redesigned or relocated, as appropriate. The mounding analysis must provide details and supporting documentation on the methods used and assumptions made, including values used in calculations. For further information on the required groundwater mounding assessment, *see Chapter 13*.

- ▪ In cases where additional storage is needed, a stone bed may be included below the soil bed to provide the additional storage.

The illustration below shows a bioretention system designed to infiltrate.

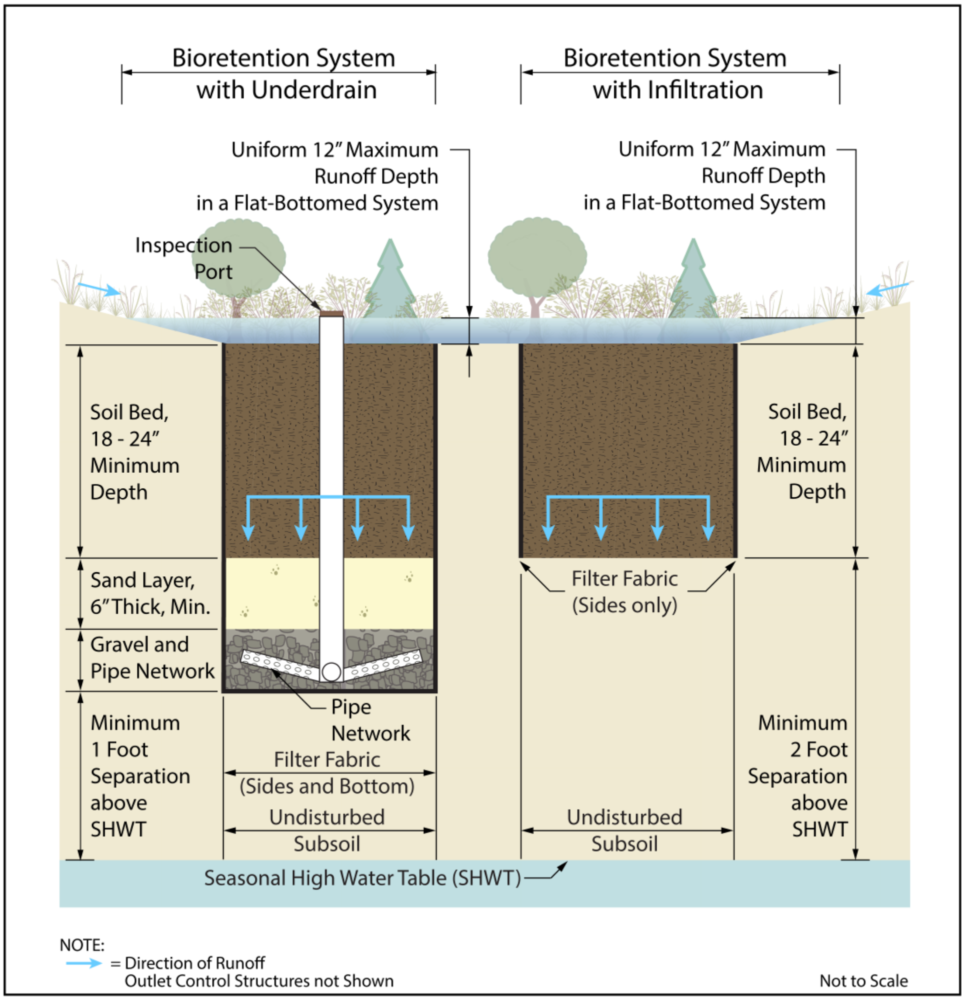
Bioretention System with Infiltration - Profile View



A Side by Side Comparison of the Two Types of Bioretention Systems

The following illustration shows the differences between the basic components of a bioretention system with an underdrain and one designed to infiltrate.

Cross Section Views – A Comparison of the Two Types of Bioretention Systems

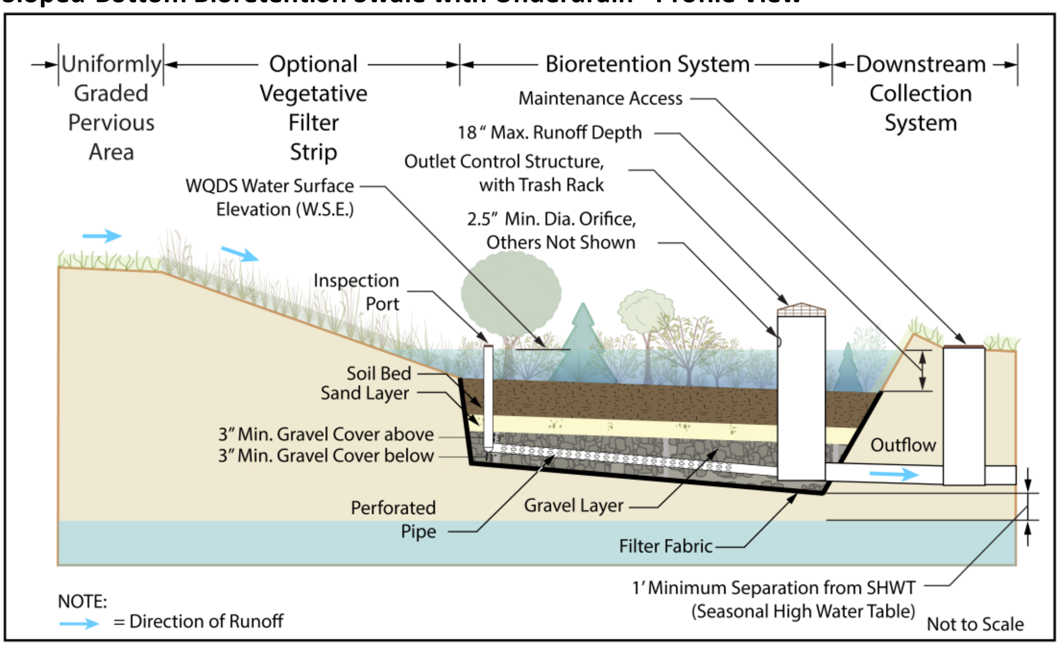


Bioretention Swale Requirements

Bioretention systems may also be designed as open channel conveyance systems, and in such instances they may be referred to as bioretention swales or bioswales. The following design criteria must all be met for a bioretention swale to merit the approved TSS removal rate.

- In sloped-bottom systems, the maximum longitudinal slope is 10%.
- If the inlet to a bioretention swale consists of a trench cut across a sidewalk, the trench must be covered by a heavy duty grate or solid cover to ensure pedestrian safety. The cover must be removable to allow maintenance of the trench.
- If the inflow to a bioretention swale consists of a curb-cut, depressed curb or other type of inlet to intercept and collect runoff directly from the street or parking lot surface, provisions must be included in the design to ensure that runoff does not pond around the inlet in such a manner that could be hazardous to vehicular and pedestrian traffic.
- For the WQDS, the maximum depth of runoff is 18 inches at the down-gradient end of a sloped-bottom system, when designed in accordance with the other design criteria found in this chapter.
- The graphic below shows a configuration of a bioretention swale with an underdrain. Note that the system has a sloped bottom. The perforated underdrain pipe must have the 3 inch minimum thickness of gravel cover above and below. The outlet control structure also serves as the down-gradient inspection port. Additional maintenance access is provided at the connection to the downstream stormwater collection system.

Sloped-Bottom Bioretention Swale with Underdrain - Profile View



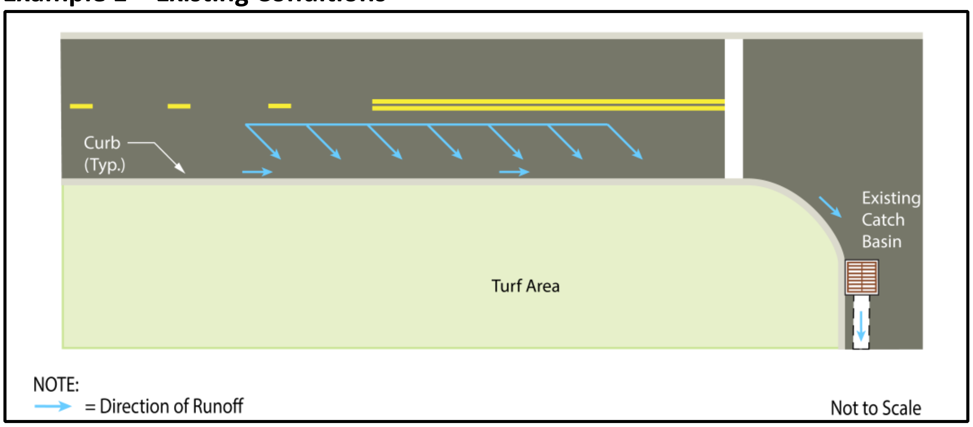
Designing a Bioretention System

The following examples show how to design various bioretention systems to treat the runoff generated by the WQDS. The examples below are two of many possible ways to configure these systems and are not intended to limit the design.

Example 1: For the existing two-lane curbed regulated motor vehicle surface illustrated below, design a bioretention basin to infiltrate the runoff generated by the WQDS. Runoff will enter the proposed system as flow piped from a new shallow catch basin situated along the curb line, and overflow will discharge to the existing stormwater collection system. The following parameters apply:

Inflow Drainage Area =	120,000 sf of motor vehicle surface
Pavement NRCS Curve Number (CN) =	98
Soil Bed Depth =	18 inches
Tested Permeability of Soil Bed =	8 inches/hour
Tested Permeability of Subsoil =	2 inches/hour
Depth to the Seasonal High Water Table =	8 ft

Example 1 – Existing Conditions



Step 1: Runoff Calculations

Using the NRCS method described in *National Engineering Handbook*, *Part 630* (*NEH*) and discussed in *Chapter 5: Stormwater Management Quantity and Quality Standards and Computations*, the volume of runoff produced by the WQDS was calculated to be 10,344 cf.

Step 2: Sizing the Bioretention System

In accordance with the design criteria for this type of system, the maximum depth of runoff above the surface of the soil bed is 2 ft. Therefore, the surface area required to infiltrate the WQDS volume of runoff from Step 1 is 5,172 sf.

Step 3: Estimated Drain Time Calculation

The drain time is determined by the permeability of the soil bed and the subsoil. The tested permeability of the subsoil is 2 in/hr, which results in a design permeability of 1 in/hr. The design permeability of the soil bed is 4 in/hr; therefore, the permeability of the subsoil is the limiting factor. Because the majority of runoff infiltration occurs through the subsoil, estimation of drain time may only be considered for the basin bottom. For the WQDS, the drain time is calculated as follows:

$$Drain\ Time = \frac{Water\ Quality\ Design\ Storm\ Runoff\ Volume}{Surface\ Area\ x\ Subsoil\ Design\ Permeability\ Rate}$$

$$= \frac{10{,}344\ cf}{(5{,}172\ sf\ x\ 1\ inch/hour\ x\ 1\ ft/12\ inches)} = 24\ hours$$

Since this is less than the allowable maximum drain time of 72 hours, the bioretention system appears, at this stage, to meet the drain time requirements.

Step 4: Check Separation from SHWT

The vertical distance between the lowest elevation of the soil bed and the SHWT must be checked to ensure it meets the minimum requirements. By inspection, 2 ft basin depth plus 1.5 ft soil bed depth plus 2 ft separation is less than the 8 ft available.

Step 5: Groundwater Mounding Analysis

Calculate the height of the groundwater mound caused by infiltration to ensure that it will neither prevent infiltration nor damage nearby structures. For information on conducting a groundwater mounding analysis, please see *Chapter 13*. For this example, it is assumed the design meets the necessary groundwater mound requirements.

Step 6: Overflow Configuration

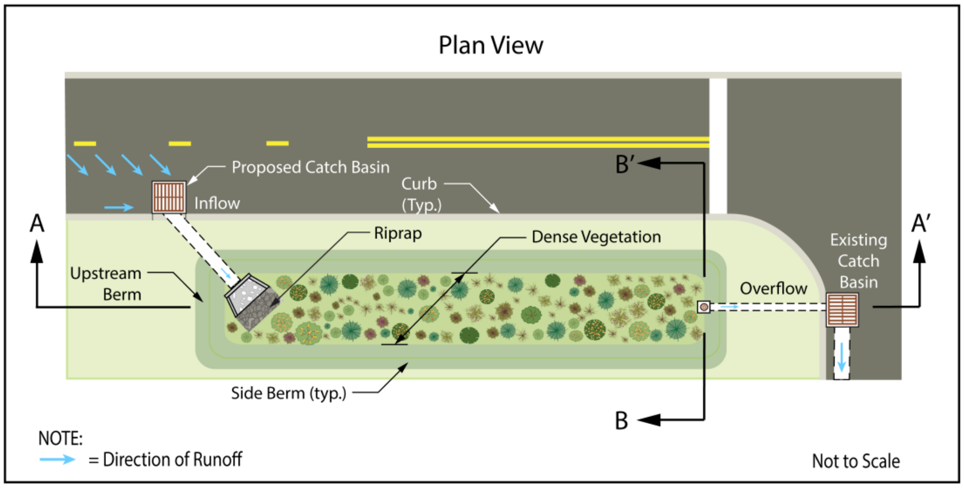
The bioretention system in this example is an on-line system. On-line systems receive runoff from all storms events, and they convey the runoff from larger storms through an overflow, which, in this example, consists of a berm and an overflow riser. The opening in the riser is set at an elevation 1 foot above the surface of the soil bed; this design allows the accumulation of runoff up to the WQDS elevation to infiltrate; excess runoff discharges through the overflow pipe, which is fitted with a debris cap to protect the opening from becoming clogged with vegetative matter and trash.

Step 7: Refinements to Design

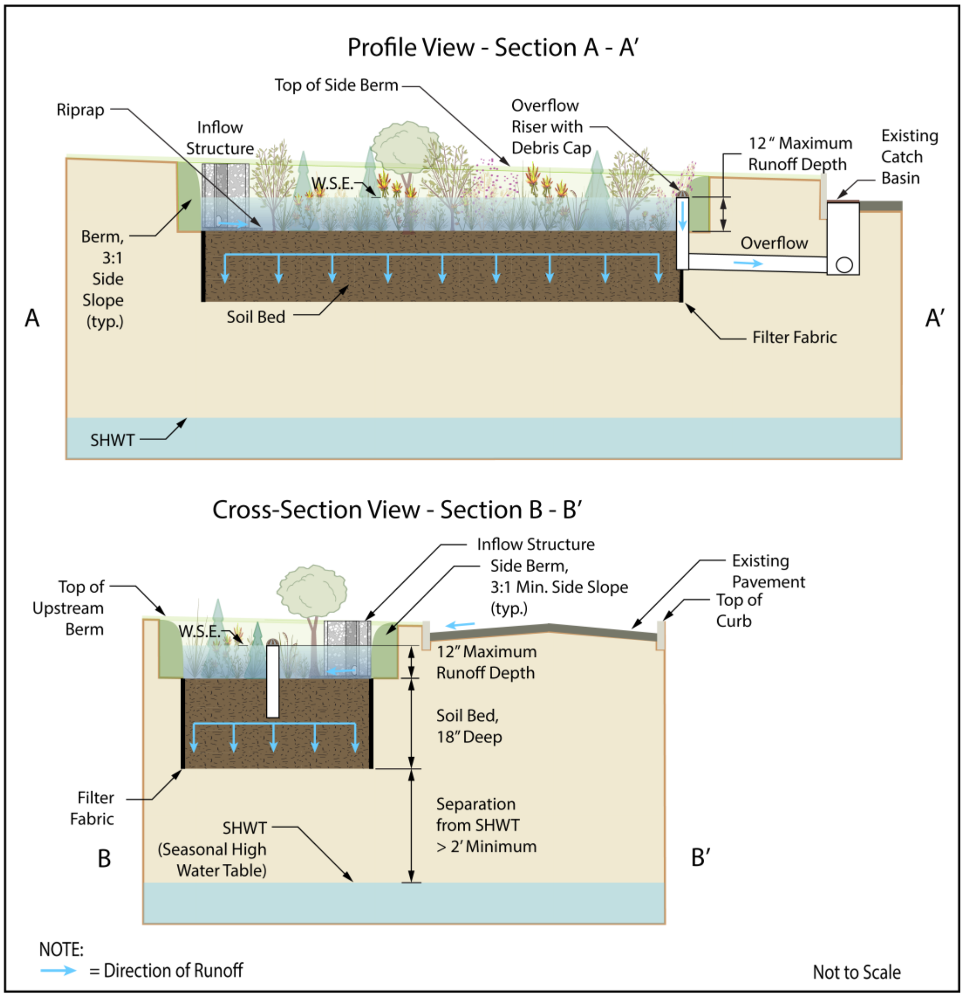
The bioretention system in this example includes earthen embankments. Therefore, the overall size of the system will have to account for the required 3:1 minimum side slopes. As-built testing must be conducted to validate the assumptions in the problem statement, confirm the design permeability rate of the subsoil and memorialize the design drain time of the system in the maintenance plan.

The following illustrations show this bioretention system in plan, profile and cross sectional views. Take note that the horizontal distance between the inflow and outflow riser allows for maximum contact time between the runoff and the vegetation, which promotes greater pollutant removal.

Example 1 - Plan View



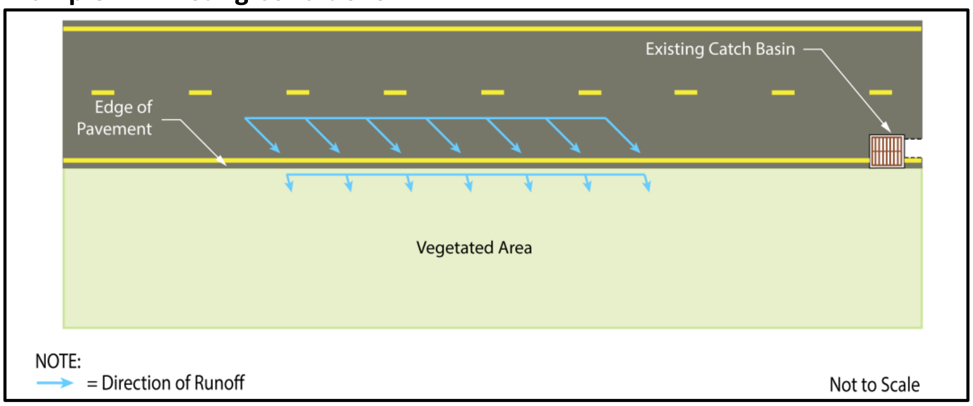
Example 1 - Profile and Cross-Section View



Example 2: For the existing uncurbed section of regulated motor vehicle surface illustrated below, design a bioretention swale with an underdrain to treat the runoff generated by the WQDS. Runoff will enter the proposed system as overland flow from the adjacent road surface. Additionally, a connection to the existing downstream stormwater collection system will be required in order to maintain safe travel conditions. The following parameters apply:

Inflow Drainage Area =	110,000 sf of motor vehicle surface
Pavement NRCS Curve Number (CN) =	98
Soil Bed Depth =	18 inches
Assumed Design Permeability of Soil Bed =	4 inches/hour
Water Quality Design Storm Depth =	18 inches = 1.5 feet

Example 2 – Existing Conditions



Step 1: Runoff Calculations

Using the NRCS method described in *National Engineering Handbook, Part 630 (NEH)* and discussed in *Chapter 5*, the volume of runoff produced by the WQDS was calculated to be to be 9,482 cf.

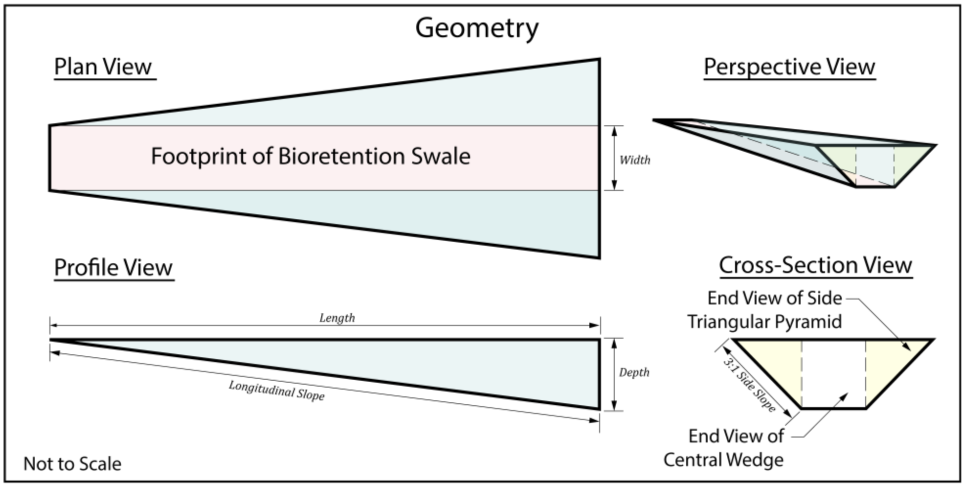
Step 2: Preliminary Shape and Size of the Bioretention Swale

For an initial approximation, a simple shape is selected. If the swale is represented by a wedge shape, the surface area of the soil bed can be estimated by dividing the runoff volume from Step #1 by the average depth of runoff in the swale. For the WQDS, the upstream depth is set at zero, and the surface area is calculated as follows:

$$Surface\ Area\ = \frac{9{,}482\ cf}{(0.5\ x\ 1.5\ ft)} = 2{,}530\ \text{sf}$$

However, the swale cross-section cannot be rectangular. That would create a sharp drop-off adjacent to the roadway, resulting in erosion of the soil bed. The nature of the flow as it enters the bioretention swale, as well as the nature of future maintenance tasks that will be required, must be taken into account when designing a bioretention swale. A more complex shape must be evaluated and checked for compliance with the minimum SHWT separation requirement; therefore, the assumed shape is a flat-bottom swale with sloping sides. In this configuration, the longitudinal slope directs runoff toward the downstream end, and the collected runoff forms a prismatic shape with a trapezoidal downstream face. This shape can be thought of as a central wedge flanked by two symmetrical triangular pyramids, shown in the following illustration. The ends of the two pyramids are shaded in yellow and that of the central wedge in white in the cross-section view.

Example 2: Geometry



Runoff will occupy not only the footprint of the swale, shown in pink in the plan view portion of the above illustration, but also the two side pyramids shown in blue. Failure to account for this additional volume results in both an oversized swale and the infiltration, during larger storm events, of more volume than allowed. Calculating the volume of this complex shape by hand, although possible, is beyond the scope of this chapter and is easily performed by computer programs.

Step 3: Estimated Drain Time Calculation

Since there is no infiltration into the subsoil, the limiting factor in the drain time calculation is the permeability rate of the soil bed. If the method employed in Step #3 of Example 1 was followed, the assumed soil bed design permeability and the footprint area shaded above in pink would determine the drain time. Following Example 1, an estimate of the drain time for the WQDS would be calculated as follows:

$$Drain\ Time = \frac{Water\ Quality\ Design\ Storm\ Runoff\ Volume}{Footprint\ Area\ x\ Soil\ Bed\ Design\ Permeability\ Rate}$$

However, the above method cannot be used because the swale has a sloped bottom, meaning the area available for infiltration will vary with time as the water level decreases. The area available for infiltration that is present at any given moment is a function of the depth of the runoff in the swale at that moment. The drain time calculation could be written as a summation of all the incremental volumes divided by the soil bed permeability rate, but in the end, the maximum design depth governs the calculation. The drain time estimate is therefore as follows:

$$Drain\ Time = \frac{Maximum\ Runoff\ Depth}{Soil\ Bed\ Design\ Permeability\ Rate}$$

$$= \frac{18\ inches}{4\ inches/hour} = 4.5\ hours$$

Since this is less than the allowable maximum drain time of 72 hours, the bioretention system appears, at this stage, to be sized correctly to meet the drain time requirements.

Step 4: Overflow Configuration

The bioretention swale in this example is an on-line system. On-line systems receive runoff from all storms events, and they convey the runoff from larger storms through an overflow, which, in this example, consists of a berm and an overflow riser. The opening in the riser is set at an elevation 1.5 feet above the surface of the soil bed; this design allows the accumulation of runoff up to the WQDS elevation to infiltrate; excess runoff discharges through the overflow pipe, which is fitted with a debris cap to protect the opening from becoming clogged with vegetative matter and trash.

Step 5: Underdrain Design

To ensure that the underdrain does not provide the hydraulic control of the system, the pipe network must be designed with conveyance rates at least twice as fast as the design flow rate through the sand layer. Additionally, the pipes must be sloped for complete drainage. The required clearances within the gravel layer must also be provided.

Step 6: Check Separation from SHWT

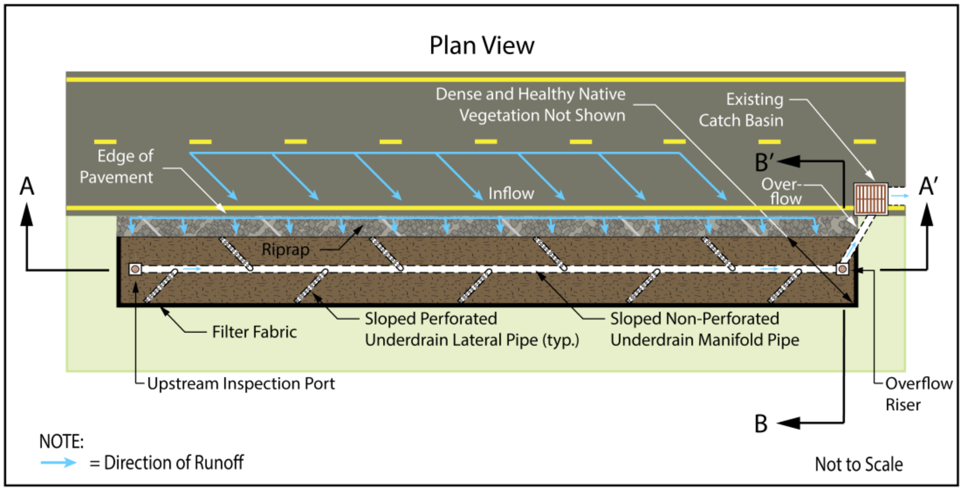
The vertical distance between the lowest elevation of the gravel layer and the SHWT must be checked to ensure it meets the minimum 1 ft separation requirement.

Step 7: Refinements to the Design

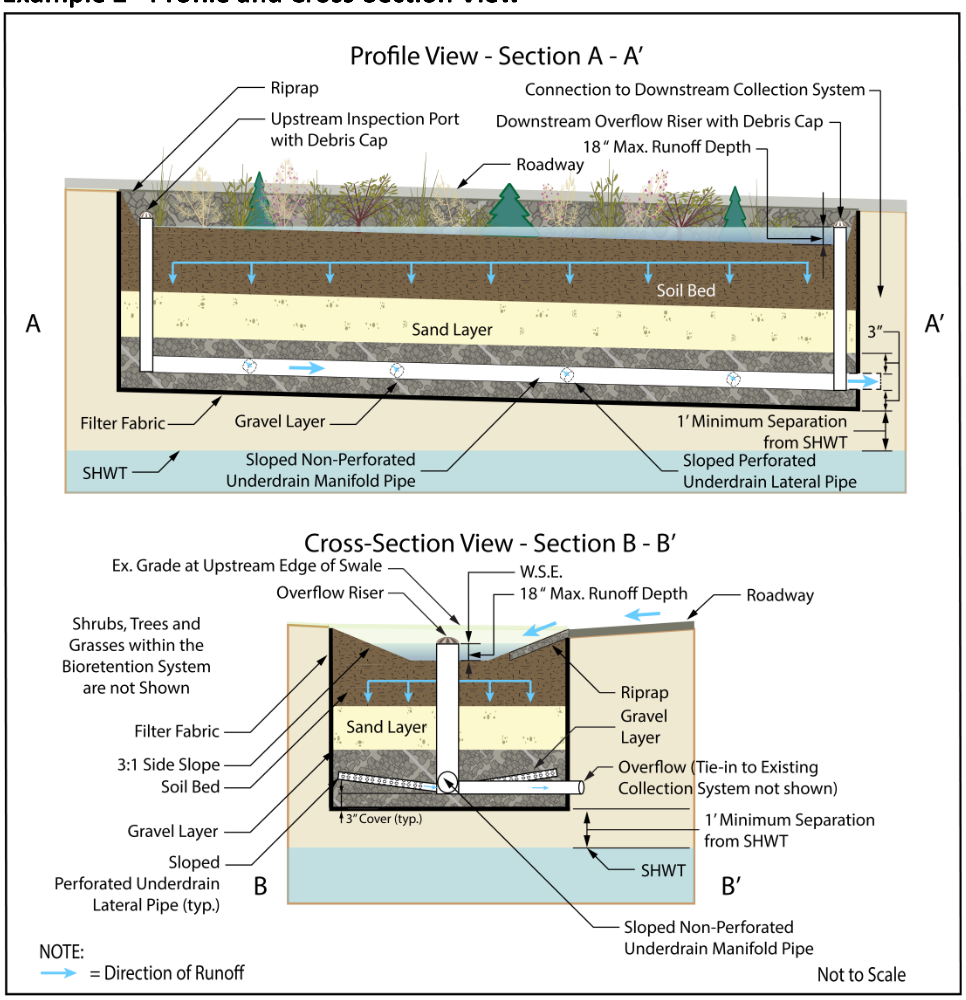
The overall size of the system will have to account for the two triangular pyramids on the sides which have a 3:1 slope. Additionally, rip-rap is placed between the bioretention swale and the edge of pavement to prevent erosion. Prior to installation of the soil bed, permeability testing is not feasible; therefore, for design calculations, a permeability rate of 4 inches/hour was assumed. This assumed permeability rate included the required factory of safety, which translates to an assumed tested permeability rate of 8 inches/hour. As-built testing must be conducted to validate this assumption and establish the design drain time of the system, which must also be included in the maintenance plan.

The illustrations on the following page show this bioretention swale in plan, profile and cross sectional views. In this example, an additional vertical space above the outflow riser, although not required, is included. This additional vertical space is intended to ensure that the swale does not flood the roadway in the event that debris partially clogs the cap on the overflow riser. This additional space does not increase the volume of runoff infiltrated, as the opening in the outflow riser directs excess runoff to the downstream collection system. The overall size of the swale in this example includes end berms as transition areas to the existing grade elevation to account for this additional depth.

Example 2 - Plan View



Example 2 - Profile and Cross-Section View



Considerations

When planning a bioretention system designed to infiltrate into the subsoil, consideration should be given to soil characteristics, depth to the groundwater table, sensitivity of the region, and inflow water quality. It is also important to note that the use of systems designed to infiltrate into the subsoil is recommended in this manual only where the WQDS or smaller storm events are contained below the first outlet control structure. Use of these systems to store larger volumes below the first outlet control structure should only be considered when another applicable rule or regulation requires the infiltration of a larger storm event. In such a case, the bioretention system should be designed to store the minimum storm event required to address that rule or regulation, below the first outlet control structure.

In addition to the prohibition of recharge in the areas with high pollutant loading or with runoff exposed to source material as defined in N.J.A.C. 7:8-5.4(b)3, the utilization of bioretention systems should consider the impact of infiltration on subsurface sewage disposal systems, water supply wells, groundwater recharge areas protected under the Ground Water Quality Standards rules at N.J.A.C 7:9C, streams under antidegradation protection by the Surface Water Quality Standards rules at N.J.A.C. 7:9B or similar facilities or areas geologically and ecologically sensitive to pollutants or hydrological changes. Furthermore, the location and minimum distance of the bioretention basin from other facilities or systems shall also comply with all applicable laws and rules adopted by Federal, State and local government entities.

Geology

The presence or absence of Karst topography is an important consideration when designing a bioretention system designed to infiltrate into the subsoil; in areas of the State with this type of geology, the bedrock is composed of highly soluble rock. If Karst topography is present, infiltration of runoff may lead to subsidence and sinkholes; therefore, only bioretention systems designed with underdrains should be used in these areas. For more information on design and remediation in areas of Karst topography, refer to the *Standards for Soil Erosion and Sediment Control in New Jersey: Investigation, Design and Remedial Measures for Areas Underlain by Cavernous Limestone.*

Pretreatment

As with all other best management practices, pretreatment may extend the functional life and increase the pollutant removal capability of a bioretention system by reducing incoming velocities and capturing coarser sediments.

- Pretreatment may consist of a forebay or any of the BMPs found in *Chapters 9 or 11*.
- There is no adopted TSS removal rate associated with forebays; therefore, their inclusion in any design should be solely for the purpose of facilitating maintenance. Forebays may be earthen, constructed of riprap, or made of concrete and must comply with the following requirements:
    - □ The forebay must be designed to prevent scour of the receiving basin by outflow from the forebay.
    - □ The forebay should provide a minimum storage volume of 10% of the WQDS and be sized to hold the sediment volume expected between clean-outs.

- □ The forebay should fully drain within nine hours in order to facilitate maintenance and to prevent mosquito issues. Under no circumstances should there be any standing water in the forebay 72 hours after a precipitation event.
- □ Surface forebays must meet or exceed the sizing for preformed scour holes in the *Standard for Conduit Outlet Protection* in the *Standards for Soil Erosion and Sediment Control in New Jersey* for a surface forebay.
- □ If a concrete forebay is utilized, it must have at least two weep holes to facilitate low level drainage.

- When using another BMP for pretreatment, it must be designed in accordance with the design requirements outlined in its respective chapter. For additional information on the design requirements of each BMP, refer to the appropriate chapter in this manual.

- Any roof runoff that discharges to the bioretention system may be pretreated by leaf screens, first flush diverters or roof washers. For details of these pretreatment measures, see Pages 5 and 6 of *Chapter 9.1: Cisterns.*

Mulch Layer

The mulch layer on the surface of the soil bed may enhance the performance of the bioretention system. Mulch can aid in plant growth by retaining moisture and by providing an environment for microorganisms that decompose incoming organic matter. Additionally, the mulch layer can act as a filter for finer particles in runoff preventing these particles from clogging the soil bed.

- Care must be taken to ensure that the mulch layer does not reduce the design permeability rate of the surface.

- The mulch layer should consist of standard 1 to 2 inch shredded hardwood or chips.

- The mulch layer should be 2 to 4 inches in depth and replenished as necessary.

- To determine whether a mulch layer is appropriate for on-line systems, consideration must be given to issues such as scour and floatation of the mulch during large storm events.

Enhancing Pollutant Removal

- Maximizing the horizontal distance between inflow and overflow structures in a bioretention system may increase contact time for stormwater runoff with the system vegetation and soil bed, where pollutant-removing chemical and biological processes occur. Grouping inflows near outflows may locally decrease the capacity of the soil bed to remove metals and other dissolved nutrients as well as the ability of the plants to uptake pollutants.

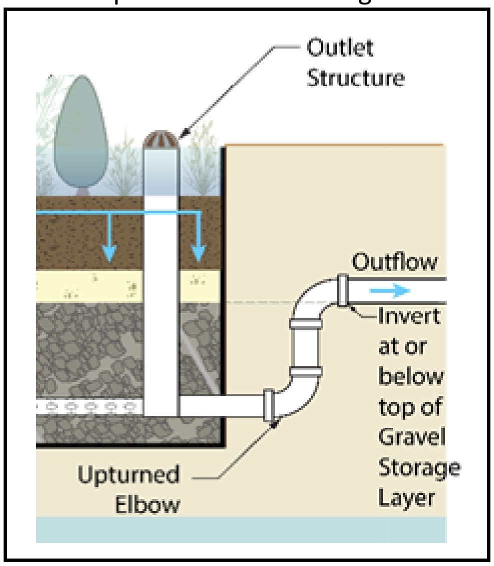
- Increasing the soil bed depth to 25 - 36 inches may enhance pollutant removal and accommodate more deeply-rooted plants.

- The organic content shall be mature (carbon/nitrogen ratio (C:N) less than or equal to 25.) The phosphorus content of the blended soil bed material should not be excessive, available P by Mehlich-3 method should be between 25 to 100 mg/kg. The cation exchange capacity (CEC) shall be greater than or equal to 5 milliequivalents/100g dry soil.

- The designer may wish to include soil amendments to target the removal of pollutants of concern. For example, biochar is one such soil amendment. If this is the case, links or references to the supporting research should be included in the stormwater management report narrative. The designer is encouraged to contact the Department to discuss this issue further. The maintenance plan must include costs and tasks associated with periodic replacement of any amendments.

- For systems with an underdrain, the designer may wish to include the upturned elbow configuration shown in the illustration below to slow the discharge and increase the potential for increased biological processes to occur in the gravel layer.

Detail: Upturned Elbow Configuration



Soil Characteristics

For bioretention systems designed to infiltrate into the subsoil, soils are perhaps the most important consideration for site suitability. In general, County Soil Surveys may be used to obtain necessary soil data for planning and preliminary design of bioretention systems. However, as previously mentioned, for final design and construction, soil tests are required at the exact location of the proposed system in order to confirm its ability to function properly without failure. In order to confirm reasonable data consistency, the results of soil testing should be compared with the County Soil Survey data that was used in the computation of runoff rates and volumes and the design of on-site BMPs. If significant differences exist between the soil test results and the County Soil Survey data, additional soil tests are recommended to determine and evaluate the extent of the data inconsistency and whether there is a need for revised site runoff and BMP design computations. All significant inconsistencies should be discussed with the local Soil Conservation District prior to proceeding with such a redesign to help ensure that the final site soil data is accurate.

Maintenance

Regular and effective maintenance is crucial to ensure effective bioretention system performance; in addition, maintenance plans are required for all stormwater management facilities on a major development. There are a number of required elements in all maintenance plans, pursuant to N.J.A.C. 7:8-5.8; these are discussed in more detail in *Chapter 8: Maintenance of Stormwater Management Measures*. Furthermore, maintenance activities are required through various regulations, including the New Jersey Pollutant Discharge Elimination System (NJPDES) rules, N.J.A.C. 7:14A. Specific maintenance requirements for bioretention systems are presented below; these requirements must be included in the maintenance plan.

General Maintenance

- Proper and timely maintenance is essential to continuous, effective operation; therefore, an access route must be incorporated into the design, and it must be properly maintained.
- All structural components must be inspected, at least once annually, for cracking, subsidence, spalling, erosion and deterioration.
- Components expected to receive and/or trap debris and sediment must be inspected for clogging at least four times annually, as well as after every storm exceeding 1 inch of rainfall.
- Sediment removal should take place when all stormwater runoff has drained from the planting bed and the basin is dry.
- Disposal of debris, trash, sediment and other waste material must be done at suitable disposal/recycling sites and in compliance with all applicable local, state and federal waste regulations.
- In systems with underdrains, the underdrain piping must be connected, in a manner that is easily accessible for inspection and maintenance, to a downstream location.
- Access points for maintenance are required on all enclosed areas within a bioretention system; these access points must be clearly identified in the maintenance plan. In addition, any special training required for maintenance personnel to perform specific tasks, such as confined space entry, must be included in the plan.
- Stormwater BMPs may not be used for stockpiling of plowed snow and ice, compost, or any other material.
- A detailed, written log of all preventative and corrective maintenance performed on the bioretention system must be kept, including a record of all inspections and copies of maintenance-related work orders. Additional maintenance guidance can be found at https://www.njstormwater.org/maintenance_guidance.htm.

Vegetated Areas

- Bi-weekly inspections are required when establishing/restoring vegetation.

- A minimum of one inspection during the growing season and one inspection during the non-growing season is required to ensure the health, density and diversity of the vegetation.

- Mowing/trimming of vegetation must be performed on a regular schedule based on specific site conditions; perimeter grass should be mowed at least once a month during the growing season.

- Grasses within the bioretention system must be carefully maintained with lightweight equipment, such as a hand-held line trimmer, in order to maintain the permeability of the system.

- Vegetative cover must be maintained at 85%; damage must be addressed through replanting in accordance with the original specifications.

- Vegetated areas must be inspected at least once annually for erosion, scour and unwanted growth; any unwanted growth should be removed with minimum disruption to the remaining vegetation.

- All use of fertilizers, pesticides, mechanical treatments and other means to ensure optimum vegetation health must not compromise the intended purpose of the bioretention system.

Drain Time

- The planting bed must be inspected at least twice annually to determine if the permeability of the bed has decreased.

- The design drain time for the maximum design storm runoff volume must be indicated in the maintenance manual.

- If the actual drain time is longer than the design drain time, the components must be evaluated and appropriate measures taken to return the bioretention system to the original tested as-built condition.

- If the bioretention system fails to drain the WQDS within 72 hours, corrective action must be taken and the maintenance manual revised accordingly to prevent similar failures in the future.

- The water surface elevation for each of the design storms must be indicated on the maintenance plan and in the maintenance logs to facilitate inspections. It is suggested that indelible markings be drawn or physical markers be set on the inside of the outlet control structure as visual indicators of the design storm water surface elevations.

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