9.7 SMALL-SCALE BIORETENTION SYSTEMS

Small-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 runoff can infiltrate into the subsoil. Pollutants are treated through the processes of settling, plus 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
	Groundwater Recharge	Yes, for systems designed to infiltrate into the subsoil
	Stormwater Runoff Quality	80 - 90% TSS Removal, depending on vegetation selection and depth of the soil bed

Water Quality Mechanisms and Corresponding Criteria	
Settling	
Minimum Storage Volume	Entire Water Quality Design Storm Volume
Vegetative Uptake and Filtration	
Minimum Density of Vegetation	85%
Appropriate Species Selection	See Page 5 and *Chapter 7: Landscaping*
Depth of Soil Bed	1.5 - 2 feet, See Page 5
Infiltration	
Maximum Contributory Drainage Area	2.5 acres
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, tested in accordance with *Chapter 12: Soil Testing Criteria*

Introduction

Small-scale 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. Small-scale bioretention systems may also be used to reduce peak runoff rates when designed as a multi-stage, multi-function facility.

In small-scale bioretention systems designed to infiltrate into the subsoil, the rate of infiltration is affected by the permeability of the subsoil, the distance separating the system bottom from the seasonal high water table (SHWT) and the area of the system 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 small-scale 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.

Small-scale 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, 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 in accordance with N.J.A.C. 7:8-5.2(h). Additional guidance is available in *Chapter 13: Groundwater Table Hydraulic Impact Assessments for Infiltration BMPs*.

Small-scale bioretention systems manage stormwater runoff close to its source because their small scale and versatile nature allows them to fit into the limited space near the buildings or structures generating the runoff, where larger scale bioretention systems could not be used. They are used to remove a wide range of pollutants, which include suspended solids, nutrients, metals, hydrocarbons and bacteria. Additionally, they may be used to reduce the volume of runoff leaving the site. Many versions of small-scale bioretention systems exist, such as rain gardens, stormwater planters, stormwater islands, downspout planter boxes, street trenches, bioswales, enhanced and continuous tree pits or a number of other names that vary based on the shape, location and configuration of each system. Regardless of the name, small-scale bioretention systems all generally consist of a soil bed planted with vegetation, storage to temporarily detain the runoff generated by the design storm, and/or an optional outlet structure. Stormwater runoff entering the system must be evenly distributed in order to flow across the surface and then is filtered through the soil bed before discharging downstream through an underdrain system or infiltrating into the subsoil. Vegetation in the soil bed provides uptake of pollutants and runoff.

Small-scale bioretention systems function similarly to bioretention systems; however, because small-scale bioretention systems are smaller and may vary widely in shape, they are more easily incorporated into the design of sites with limited space. This flexibility allows small-scale bioretention systems to be used in various locations, including lawns, median strips, parking lot islands, and sidewalks. Because small-scale bioretention systems are intended to treat runoff close to its source, the maximum contributory inflow drainage area is 2.5 acres.

Finally, a small-scale 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 series of images depict different small-scale bioretention systems and highlight some of the features of those systems. These images are for illustrative purposes only. In urban settings, small-scale bioretention systems may look like small gardens situated on a portion of a lot, such as the small-scale bioretention systems, called rain gardens, shown in the following two photographs:

Alternatively, such systems may be constructed within a sidewalk or along a roadway, like those depicted in the following two photographs, which may be referred to as stormwater planters or rain gardens:

Small-scale bioretention systems may also be used as a conveyance system such as the bioswale in the parking median shown in the photograph below.

Small-scale bioretention systems may even be contained within a wooden or concrete box, generally called planter boxes or downspout planter boxes, as shown in the following photograph:

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.

Small-scale 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 small-scale biortention systems must be designed for stability and in accordance with the *Standards for Soil Erosion and Sediment Control in New Jersey*.

Only small-scale bioretention systems designed to infiltrate into the subsoil may be used to meet the groundwater recharge requirements. If designed with an underdrain, a small-scale bioretention system cannot be used to meet these requirements. For more information on computing groundwater recharge, see *Chapter 6: Groundwater Recharge.*

The depth of the soil bed and the type of vegetation determine the TSS removal rate, as shown in the table below. To merit the approved TSS removal rate of 80%, small-scale bioretention systems must be designed to treat the Water Quality Design Storm and in accordance with all of the following criteria.

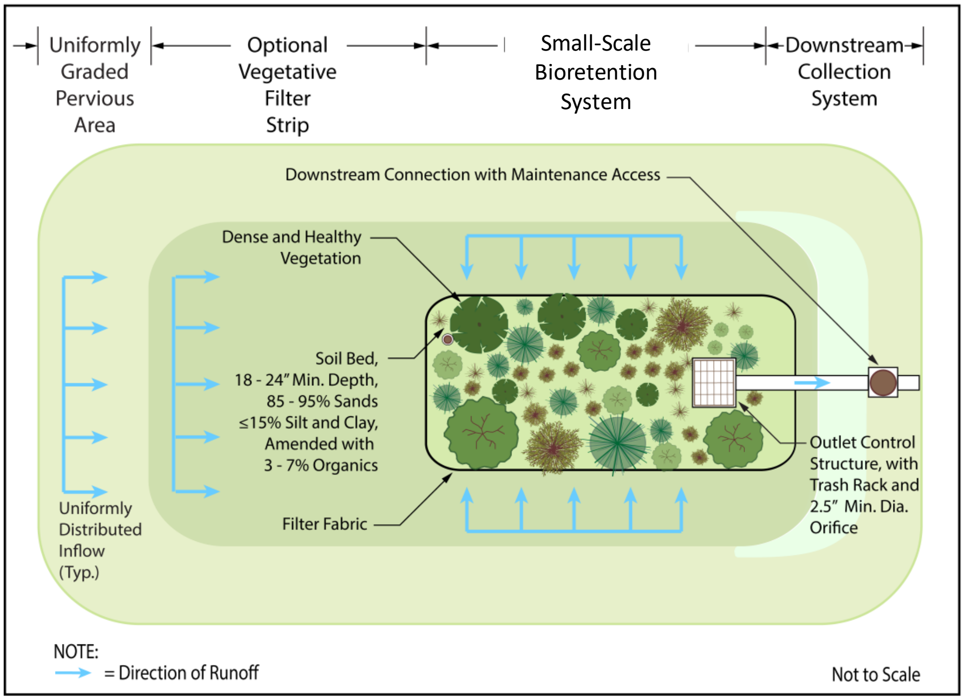
Desired TSS Removal Rate	**Design Parameters**	
	Minimum Depth of Soil Bed	**Small-scale Bioretention Vegetation**
80%	18 Inches	Terrestrial Forested Community
80%	24 inches	Site-Tolerant Grasses
90%	24 inches	Terrestrial Forested Community

Design Criteria

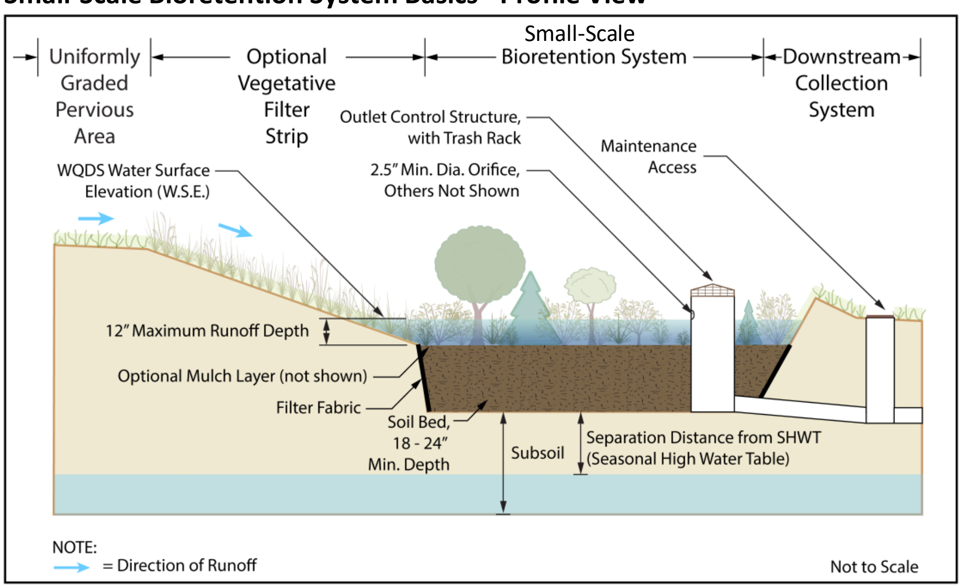
Basic Requirements

The following design criteria apply to all small-scale bioretention systems. Although the subsurface components differ, underdrained small-scale bioretention systems and those designed to infiltrate have common surface elements, which are shown below. In the following illustrations, a vegetative filter strip provides pretreatment and a downstream collection system receives runoff that does not infiltrate.

Small-Scale Bioretention System Basics - Plan View



Small-Scale Bioretention System Basics - Profile View



Additional design criteria may be found, beginning on Page 13, for a system with an underdrain and Page 17, for a system designed to infiltrate into the subsoil.

Contributory Drainage Area

- Pursuant to N.J.A.C. 7:8-5.3(b), the maximum contributory drainage area to a small-scale bioretention system is 2.5 acres.
- The entire contributory drainage area must be completely stabilized prior to use of the small-scale bioretention system.

Inflow

- All inflow must be stable and non-erosive and designed in accordance with the New Jersey Department of Agriculture's *Standards for Soil Erosion and Sediment Control in New Jersey* where applicable. A splash pad or gravel apron is recommended to prevent erosion or channelization of the soil bed.
- All inflow must be evenly distributed across the surface of the small-scale bioretention system to ensure all vegetation receives sufficient runoff during small rain events.
- For systems with multiple small-scale bioretention systems, inflow has to be distributed proportionally based on the surface area of each unit, especially when using small-scale 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 WQDS runoff volume without overflow.
- Small-scale 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 up-gradient diversion; this reduces the size of the required system 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 runoff quantity control; in such systems, the invert of the lowest quantity control outlet is set at the water surface elevation of the WQDS.
- Small-scale bioretention systems must contain only the WQDS or smaller storm events below the first outlet control structure. See Page 13 for details pertaining to an underdrained system and Page 17 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.
- Small-scale 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 small-scale bioretention system ineffective and

may result in anaerobic conditions, odor, and both water quality and mosquito breeding issues. If the small-scale bioretention system is installed in an area subject to pedestrian traffic, such as sidewalk or pedestrian accessible area in parking lot, the drain time should be reduced to 24 hours.

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 runoff is able to spread out over the entire soil bed, i.e., the system footprint.

Vegetation

- Small-scale 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 small-scale bioretention systems, see *Chapter 7: Landscapin*g. A table providing bloom information for various plants typically found in a small-scale bioretention system is included in this chapter. See Page 45.

Soil Bed

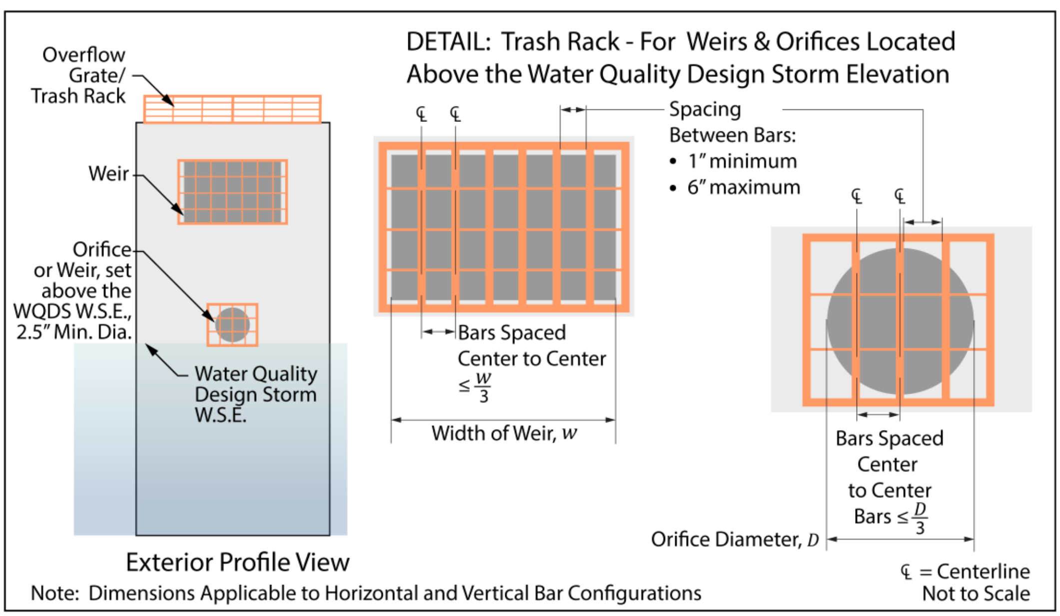
- The soil bed must be a minimum of 18 – 24 inches in depth, in accordance with the table on Page 5.
- The soil bed material must consist of the following mix, by volume: 85 to 95% sand, with no more than 25% of the sand as fine or very fine sands; no more than 15% silt and clay with 2% to 5% clay content. 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.
- For the calculation of runoff retention, the porosity, the field capacity and the wilting point of the soil bed material must be obtained either from a published research article or tested in accordance with the ASTM D-6836 method or the Soil Survey Investigations Report No. 42, Kellogg Soil Survey Laboratory Methods Manual, published by NRCS.
- The soil bed material must be placed in lifts not to exceed 6 inches. Additional materials may be necessary to account for settling over time.

Safety

- All small-scale bioretention systems must be designed to safely convey overflows to downstream drainage systems. The design of any overflow structure should 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*.
- Small-scale 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

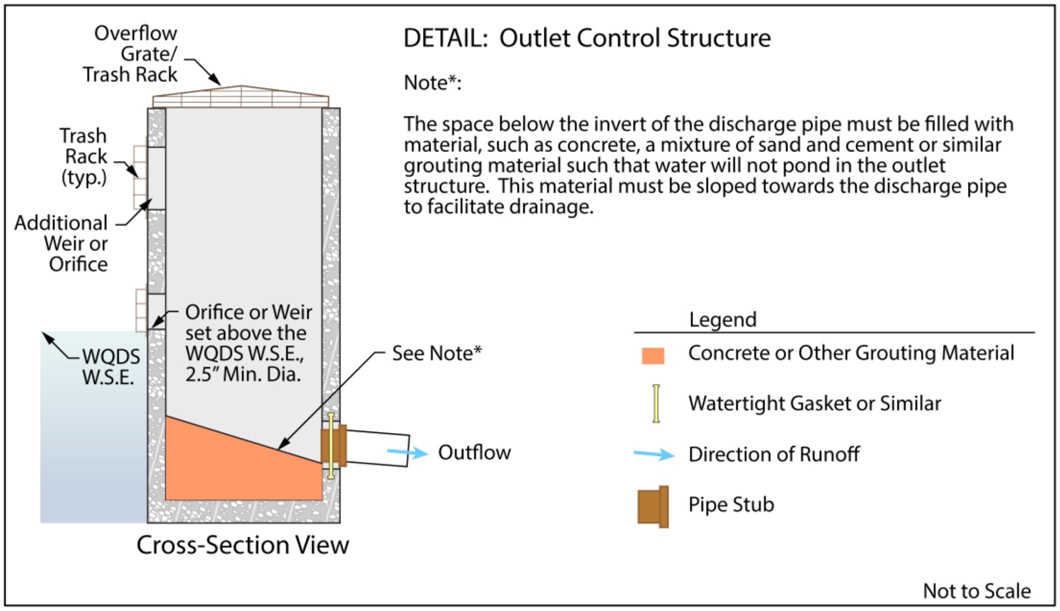
- For systems designed with an outlet structure, trash racks must be installed at the intake to the outlet structure. The outlet structure must meet the following criteria illustrated below:
  - □ Parallel bars with 1-inch spacing between the bars up to the elevation of the Water Quality Design Storm (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.

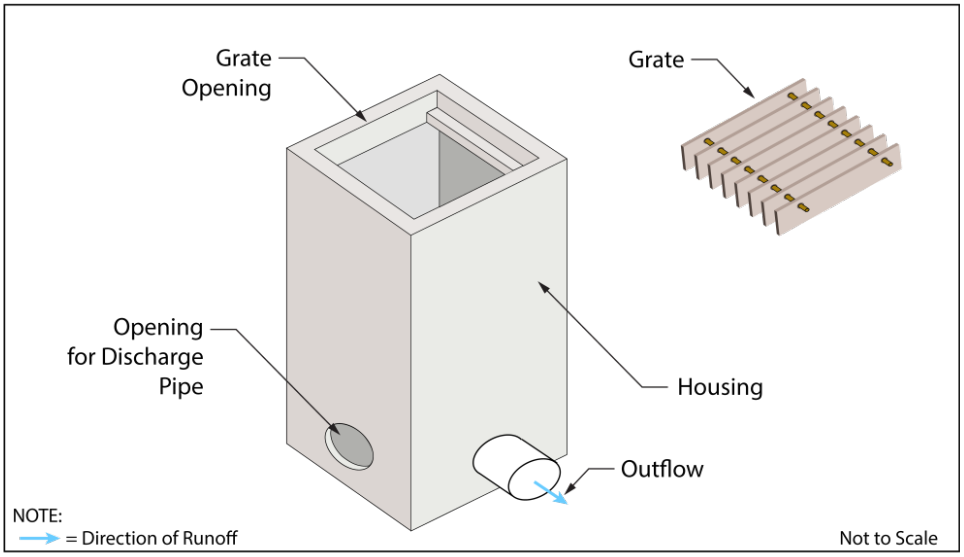


- The minimum diameter of any overflow orifice is 2.5 inches.

- Blind connections to downstream 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.

- For a smaller-sized small-scale bioretention system, a domed riser or drain specifically designed for soil beds or yards may be used as an outlet structure, such as, but not limited to, the square yard drain detail provided on the following page. Calculations must be included to demonstrate the selection complies with all other design criteria.

Square Yard Drain Detail



- 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 downstream 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- 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 small-scale 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 the proposed small-scale bioretention system.

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

- Excavation and construction of a small-scale bioretention system designed to infiltrate must be performed with equipment placed outside the limits of the basin.

- The location of the proposed small-scale 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 small-scale bioretention basin.

- The excavation to the final design elevation of the small-scale bioretention system bottom may only occur after all construction within its contributory drainage area is completed and the drainage area is stabilized. If construction of the small-scale 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 small-scale 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 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 system footprint, such as from all-terrain vehicles and utility trucks.

Types of Small-Scale Bioretention Systems

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

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

Individual Types of Small-Scale Bioretention Systems

The following section provides detailed design requirements for each type of small-scale bioretention system. The illustrations show possible configurations and flow paths and are not intended to limit the design. Additional design requirements specific to unique classes of small-scale bioretention systems are found beginning on Page 21.

Small-Scale Bioretention Systems with Underdrains

- Take note that this type of system cannot be used to infiltrate stormwater runoff into the subsoil or provide groundwater recharge. Routing calculations may not include exfiltration as a form of discharge.

- 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.

- Unlike a larger bioretention basin, the soil bed of an underdrained small-scale bioretention system is not designed to drain quickly, but to retain some volume of stormwater below the surface in the soil bed; therefore, the soil mix should fall into the category of loam or silt loam in the USDA soil textural triangle, which will be most capable of retaining stormwater while still maintaining a sufficient infiltration rate. Refer to the post-construction testing requirements found on Page 13 which must confirm the constructed system functions as designed.

- The underdrain consists of three components – the sand layer, 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 both 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). The sides of the underdrain pipes should similarly be protected by the same gravel. 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.
  - If the small-scale bioretention system with underdrain does not have an earthen bottom, .e.g. a wood box or a concrete slab, the 3 inch gravel layer below the underdrain pipe network is not required.

- □ Within the gravel layer, the network of pipes, excluding any manifolds and cleanouts, should be perforated. All remaining pipes should be non-perforated. To ensure proper system operation, the network of pipes should have a conveyance rate at least twice as fast as the design flow rate of the soil bed.
- □ 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 same conveyance system downstream of the small-scale bioretention system, provided that the overflow discharge will not backup 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 small-scale bioretention system designed with an underdrain, in conjunction with the appropriate maximum depth discussed on Page 7. 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 lastly into the underdrain pipe network. **Under no circumstances may exfiltration (infiltration into the soil below the system) be included in the routings for stormwater runoff quantity control for any small-scale bioretention system designed with an underdrain**.

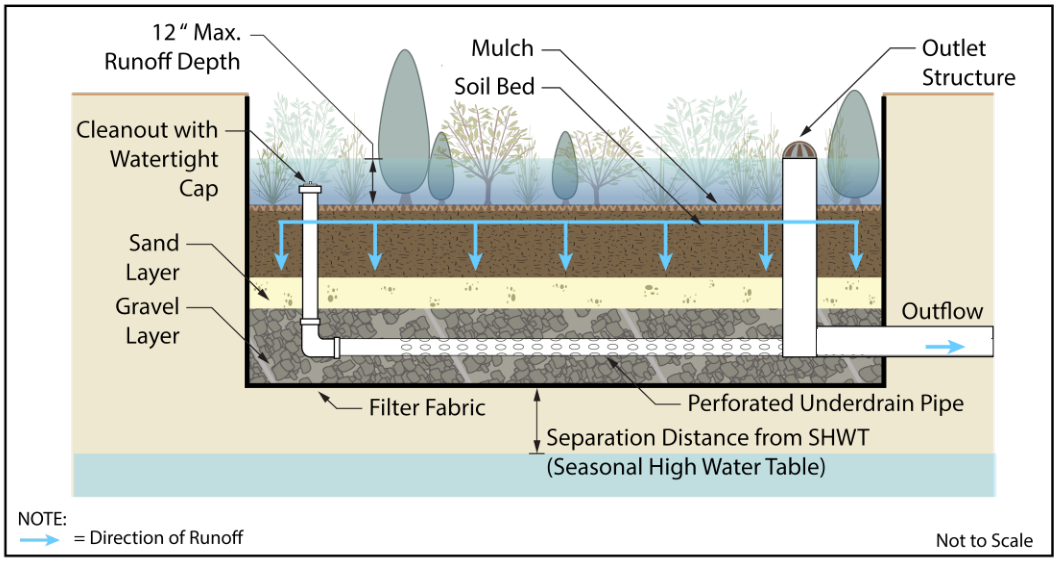
- ▪ The capacity of the underdrain must be sufficient to allow the system to drain within 72 hours, while still retaining moisture below the surface for uptake by vegetation. If the small-scale bioretention system with underdrain is installed in an area subject to pedestrian traffic, the drain time should be reduced to 24 hours.

- ▪ The seasonal high water table (SHWT) must be at least 1 foot below the bottom of the gravel layer. For small-scale bioretention systems located entirely at or above-grade and situated on impervious structures, such as those made of concrete, asphalt, or wood, this groundwater separation requirement is not applicable.

- ▪ All points of access should 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 configuration of a small-scale bioretention system with an underdrain. Although not labeled, 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.

Flat Bottom Small-Scale Bioretention System with Underdrain - Profile View



- **Volume Reduction in Small-Scale Bioretention Systems with an Underdrain**

The soil bed in a small-scale bioretention system with an underdrain will absorb and retain a portion of the runoff that is directed into it, thus reducing the volume of runoff that will reach downstream facilities. The maximum amount of water that the soil bed is capable of retaining is called the field capacity. However, in order to absorb and retain the entire field capacity, the soil bed material would need to be entirely dry at the beginning of the storm event. Since the soil bed is intended to support plant life, the soil bed material can never be completely dry or the plants would die.

The available water capacity is defined as the field capacity minus the wilting point of the plants. As such, the available water capacity is the maximum amount of water that could be retained during a storm event by a functioning small-scale bioretention system. The available water capacity is determined based upon the selected soil bed material; therefore, during design, consideration must be given to the volume reduction goals of the project. Take note the assumption that the entire available water capacity can be absorbed during each storm event assumes that the soil bed has dried to the wilting point of the plants between each storm event. Since this is unlikely to occur, a factor of safety should be applied to the available water capacity to account for the moisture above the wilting point that has been retained from the previous storm events.

Unlike the soil bed, the gravel layer does not directly support plant life and is intended to dry out entirely; therefore, the field capacity of the gravel layer is equal to the volume reduction it provides. While the gravel layer is intended to dry out completely between storm events, there is no guarantee that it will do so; therefore, a factor of safety should also be applied to the field capacity of the gravel layer.

A table providing the soil bed parameters discussed above for small-scale bioretention systems designed with an underdrain is found on the following page. This information is incorporated into the examples found on Pages 23 through 40.

Soil Parameters for Small-Scale Bioretention Systems Designed with an Underdrain

Soil Type	Total Porosity (cf/cf)	Field Capacity (cf/cf)	Wilting Point (cf/cf)	Available Water Capacity (cf/cf)	Effective Porosity (cf/cf)
Sand	0.437	0.062	0.024	0.038	0.375
Loamy Sand	0.437	0.105	0.047	0.058	0.332
Sandy Loam	0.453	0.190	0.085	0.105	0.263
Loam	0.463	0.232	0.116	0.116	0.231
Silt Loam	0.501	0.284	0.135	0.149	0.217
Sandy Clay Loam	0.398	0.244	0.136	0.108	0.154
Clay Loam	0.464	0.310	0.187	0.123	0.154
Silty Clay Loam	0.471	0.342	0.210	0.132	0.129
Sandy Clay	0.430	0.321	0.221	0.100	0.109
Silty Clay	0.479	0.371	0.251	0.120	0.108
Clay	0.475	0.378	0.265	0.113	0.097

Small-Scale Bioretention Systems Designed to Infiltrate into the Subsoil

- Exfiltration can be used in the design of a small-scale bioretention system designed to infiltrate, provided all of the conditions regarding the use of exfiltration in stormwater runoff calculations, as published in *Chapter 5: Stormwater Management Quantity and Quality Standards and Computations* are met. This information is published in the section beginning on Page 7 of *Chapter 5*, entitled "*Conditions Regarding the Use of Exfiltration in Stormwater Runoff Calculations*."

Pretreatment is a requirement for small-scale bioretention systems designed to infiltrate into the subsoil that include exfiltration in the stormwater routing calculations for the 2-, 10- and 100-year design storms.

- 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.

- For systems with inflow that is in the form of sheet or overland flow, a five foot wide gravel or stone filter strip, with a slope of no greater than 10 percent, can be substituted for the required pretreatment when exfiltration is used in the routing calculations.

- 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.*

  - The pretreatment requirement for roof runoff can be waived by the review agency if the building in question has no potential for debris and other vegetative material to be present in the roof runoff. For example, a building that is significantly taller than any surrounding trees and does not have vegetative roof should not need the pretreatment. However, in making this determination, the review agency must consider the mature height of any surrounding trees.

The following design standards apply to small-scale bioretention systems designed to infiltrate:

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

- Like larger bioretention basin, the soil bed of a small-scale bioretention system designed to infiltrate into the subsoil is designed to drain quickly while still supporting plant life; therefore, the soil mix should fall into the category of loamy sand in the USDA soil textural triangle, which will be most capable of supporting plant life while still maintaining a high infiltration rate.

- 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 small-scale 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: Soil Testing Criteria* in this manual, including the required information to be included in the soil logs, which can be found in section *2.b Soil Logs*. In accordance with *Chapter 12*, the slowest tested hydraulic conductivity 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.

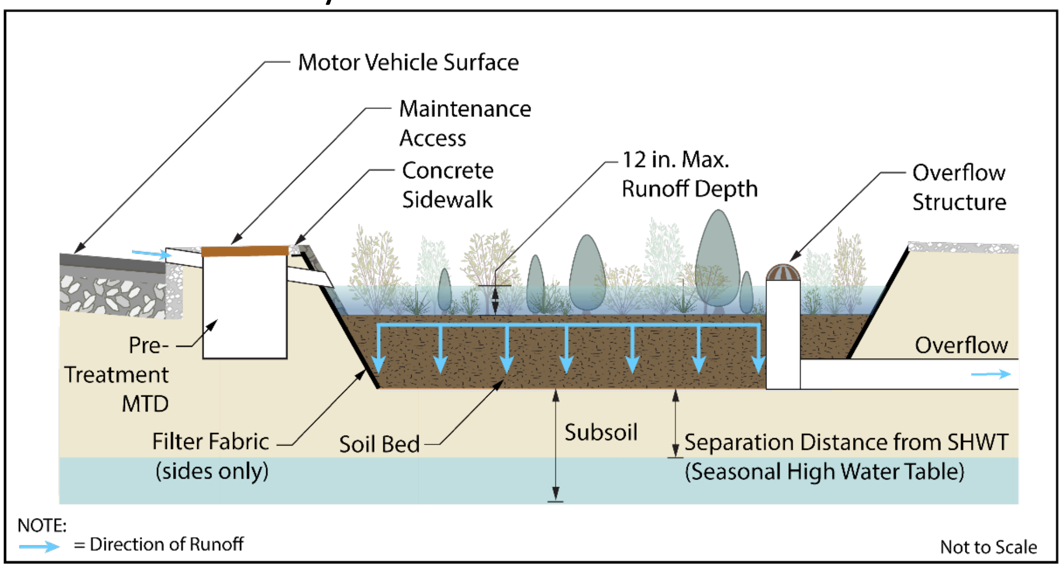
- Filter fabric is required along the sides of the soil bed to prevent the migration of fine particles from the surrounding soil if the small-scale bioretention system is located below grade and is not contained within a structure. However, unlike systems with underdrains, filter fabric may not be used 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 small-scale 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: Groundwater Table Hydraulic Impact Assessments for Infiltration BMPs*.

The illustration below shows a small-scale bioretention system designed as a rain garden to infiltrate into the subsoil. Note that an MTD is used for pretreatment so that exfiltration may be used in the stormwater routing calculations.

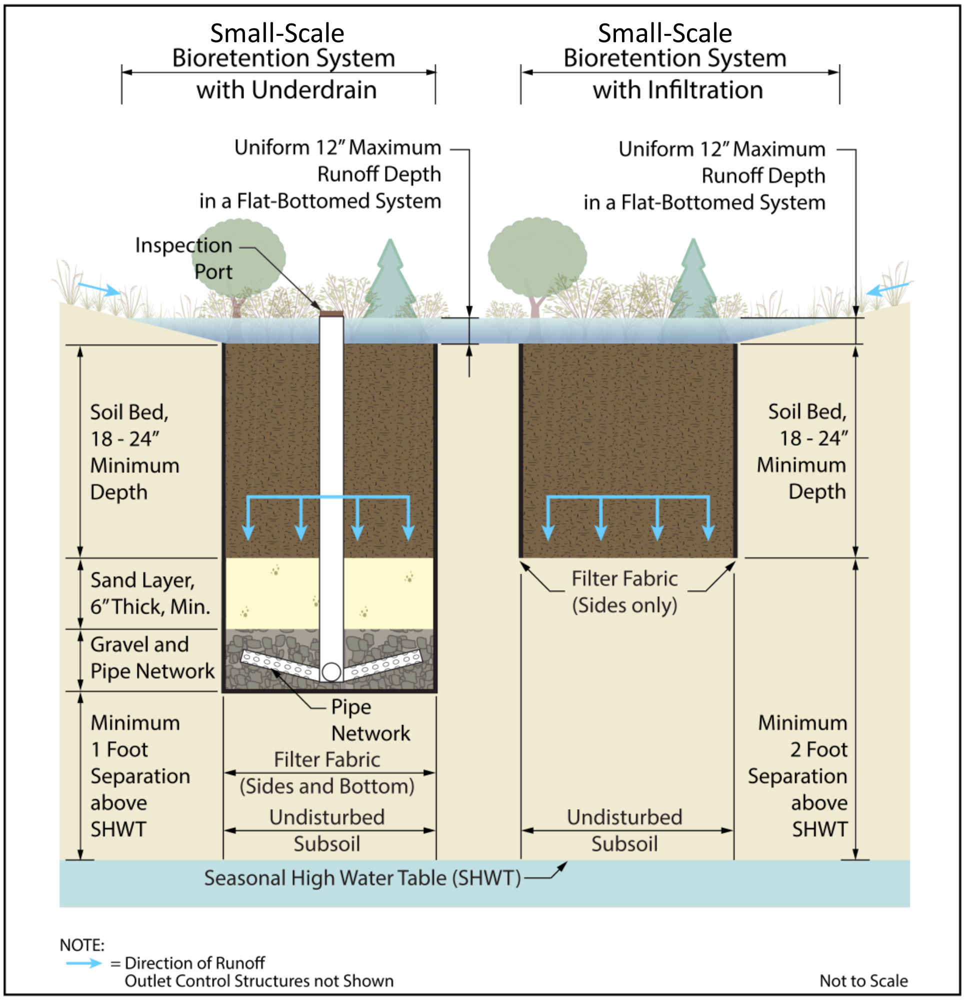
Small-Scale Bioretention System with Infiltration - Profile View



A Side by Side Comparison of the Two Types of Small-Scale Bioretention Systems

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

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



Specific Design Requirements for Different Classes of Small-Scale Bioretention Systems

In addition to the design requirements listed below, the designer may wish to incorporate or otherwise address the additional items and recommendations listed in the Considerations section, which begins on Page 41.

Aboveground Planter Box (Raised Planter Box or Downspout Planter Box)

- The downspout must have flow diversion mechanism to allow roof runoff from storms larger than the design storm to bypass the planter box.
- Overflow from the planter box must not cause surface flooding. The ground surface around the planter box must be properly graded to direct flow to a nearby stormwater collection system, lawn area, grass swale or other drainage facility.

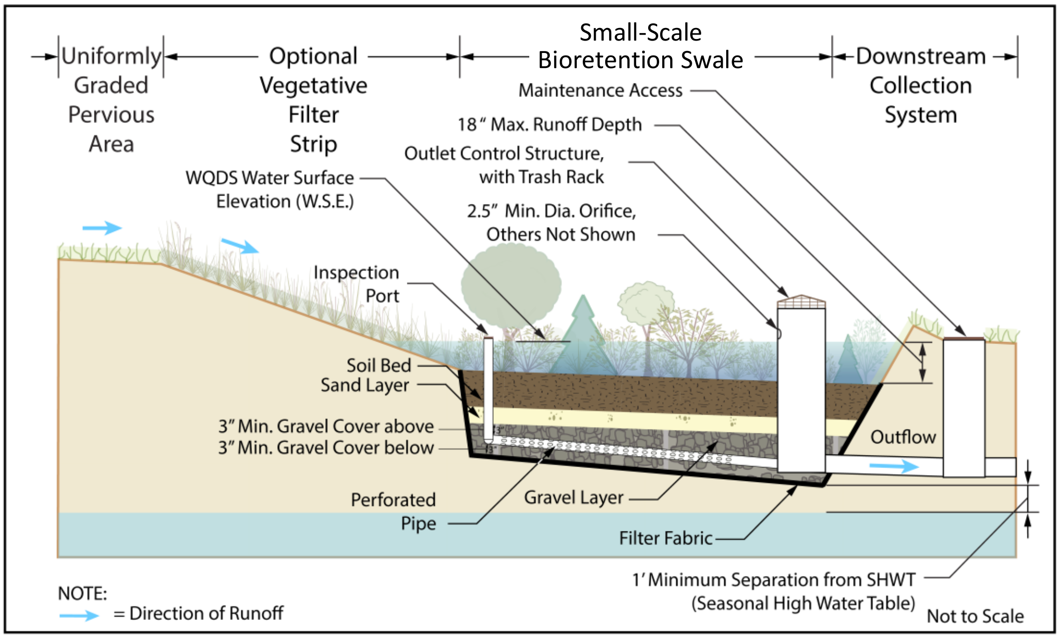
- The voids occurring between the granular components of a planter box can be included in the total storage volume of the system, as follows:
  - □ those located in the soil bed above the subsoil for small-scale bioretention systems designed to infiltrate into the subsoil, or
  - □ those in the soil bed, sand and gravel layers in small-scale bioretention systems with underdrains.
- The effective porosity shall be used to approximate the voids in the soil layers available to store runoff.
  - □ The effective porosity is the total porosity subtracted by the field capacity. Field capacity is discussed under volume reduction, beginning on Page 15.
  - □ The percentage of voids in the gravel layer is dependent on the exact gravel specification and can be looked up in a reference document. Typically, No. 2 aggregate is used, which has a void percentage of approximately 40%.

Bioretention Swale

- 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 small-scale 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 Small-Scale Bioretention Swale with Underdrain - Profile View



Stormwater Tree Pit

- A stormwater tree pit is more than a tree pit that is normally constructed on sidewalk for landscaping purposes. A stormwater tree pit must have a soil bed, as described on Page 5. Since the soil bed must support the growth of the tree, the minimum depth of 18 inches may not be sufficient. A gravel-filled storage bed for storing stormwater may also be included. Furthermore, a curb-cut, or other means, is necessary to direct street runoff into the stormwater tree pit.

- Like any other small-scale bioretention system discussed in this chapter, a stormwater tree pit may be designed to infiltrate runoff from storms less than or equal to the Water Quality Design Storm into the subsoil or to be drained through an underdrain system. Volume reduction resulting from a stormwater tree pit must be calculated as indicated in the appropriate section above, depending on whether it is designed with or without an underdrain.

- The inlet must be designed in such a manner that runoff does not pond as this would create a hazardous situation for vehicular or pedestrian traffic.

Designing a Small-Scale Bioretention System

The following examples show how to design various small-scale bioretention systems to treat the runoff generated by the Water Quality Design Storm (WQDS). The examples below represent some of the many possible ways to configure these systems and are not intended to limit the design.

Example 1: **Aboveground Planter Boxes (Downspout Planter Boxes) for Treating Roof Runoff**

An existing building is to be replaced with a garage with rooftop parking spaces. The building is part of a major development that has more than both an acre of disturbance and a quarter acre increase of motor vehicle surface. The project is located in an urban redevelopment area that has Hydrologic Soil Group D; therefore, a traditional BMP that infiltrates runoff into the subsoil would not be feasible. Because the building is in an urban area, the aesthetic appearance of the stormwater BMP is also one of the design concerns. Under these circumstances, an aboveground planter box system with underdrain is to be designed to receive stormwater runoff from the WQDS falling on the roof. Large storms will be bypassed and directed to other downstream BMPs, along with stormwater runoff generated by the access ramp and driveway.

Runoff from the parking deck will be collected by a roof drain and directed via a downspout to the planter boxes. Treated runoff will be conveyed to an underground drainage pipe to an existing stormwater collection system. The following parameters apply:

Each Inflow Drainage Area = 7,650 sf
Four (4) downspouts convey runoff to the planter boxes

Step 1: Runoff Calculations

Using the NRCS method described in *National Engineering Handbook, Part 630 (NEH)* and discussed in *Chapter 5: Stormwater Runoff Water Quantity Standards and Computations*, the volume of runoff produced by the WQDS was calculated to be 660 cf, based upon an NRCS Curve Number (CN) of 98 for impervious surfaces.

Step 2: Sizing of the Planter Boxes

a. General Capacity Calculation

Soil Bed Depth =	18 in (21.7% effective porosity for silt loam)
Assumed Design Permeability of Soil bed	1 in/hr
Sand layer =	6 in (37.5% effective porosity)
Gravel layer =	12 in (40% effective porosity)

The depth of runoff above the surface of the soil bed is 12 in. Each planter box is designed to be of uniform length and 5 ft wide. The storage volume provided by a planter box measuring internally 1 ft in length is calculated as follows:

Storage Layer	Depth (ft)	Width (ft)	Volume (cf)	Effective Volume (Effective Porosity x Volume) (cf)
Surface	1	5	5.0	100% x 5.0 = 5.0
Soil Bed	1.5	5	7.5	21.7% x 7.5 = 1.62
Sand	0.5	5	2.5	37.5% x 2.5 = 0.94
Gravel	1.0	5	5.0	40% x 5.0 = 2
Effective Volume for 1-foot long Planter Box =				**9.56 cf**

The required total length, L, of planter boxes, measured in ft, required to provide sufficient storage volume is calculated as:

$(9.56\ x\ L)\ cf \geq 660\ cf$, which simplifies to L = 69.03 ft

Instead of one long box, a total of 12 planter boxes, each 6 ft in internal length would meet our needs. Each downspout will direct runoff to 3 planter boxes.

b. Calculate the Conveyance Rate of the Underdrain Pipe and Infiltration Rate of each Layer

The underdrain pipe and the perforations must have at least twice the conveyance rate as the infiltration based on the design permeability rate of the sand layer, which is also twice the permeability rate of the soil bed (1 in/hr in this example). Therefore, calculations for the hydraulic capacity of the underdrain must be at least the 4 times of the infiltration rate provided by the soil bed (1 in/hr).

c. Design of the Connection Orifice and Pipe between the Planter Boxes

Roof-generated runoff flows into each box through a distribution manifold, which must be designed to evenly distribute runoff throughout all of the planter boxes. Runoff that cannot be infiltrated through the soil bed will fill up the storage space above the soil bed. The water depth above the soil bed should not exceed the maximum design depth of 12 inches, so an optional interconnecting pipe is used in this example to prevent overtopping of an individual unit during the maximum design storm. For the purposes of this example, assume a hydraulic analysis of the pipe was performed to ensure the passage of runoff will not overflow the tops of the planter boxes until the maximum design storm is exceeded.

Step 3: Check the surface water drain time

The soil bed permeability rate is 1 in/hr. The infiltration rate of the soil bed, for each planter box, is

$$\begin{matrix} Soil\ Bed \\ Infiltration\ Rate \end{matrix} = 6\ ft\ x\ 5\ ft\ x\ \frac{1\ in/hr}{(12\ \ in/ft)} = \text{ 2.5 cf/hr, and}$$

the drain time for the system of 12 planter boxes is calculated as shown on the following page:

$$Drain\ Time = \frac{659\ cf}{(12\ boxes\ x\ 2.5\ cf/hr)} = \text{21.97 hr}$$

Note that the calculated drain time is less than the 24-hour maximum for public areas exposed to pedestrian and driving traffic.

Step 4: Planting Plan

The plants to be considered need to tolerate inundation and grow perennially. The list below shows examples of native New Jersey plants that should be considered. A mix of the plants to prolong the period of bloom should be considered for aesthetic appearance. Additional information regarding plant choice is found in the Considerations section. The plants in the table are arranged by start of the bloom period, followed by the end of the bloom period, and then alphabetically by the most common name. An example of the planting might be as follows:

Sweet Fern (*Comptonia peregrina*)
Shrub, tolerating wet or drought conditions, blooming from April to May, green year round

Red Bearberry (*Arctostaphylos uva-ursi*)
Groundcover; well-drained soil only, perimeter planting; blooms April, May, June; evergreen year round

Common Winterberry (*Ilex verticillata*)
Shrub; tolerating inundation, blooms in April, May, June, July; fruit late fall through winter; green year round

Swamp Milkweed (*Asclepias incarnata)*
Herbaceous perennial; tolerating inundation; blooms in May, June

American Tiger Lily (*Lilium superbum*)
Herbaceous perennial; tolerating inundation; blooms in July, August, September

White Turtlehead (*Chelone glabra*)
Herbaceous perennial; tolerating seasonal inundation; blooms in July, August, September

Great Blue Lobelia (*Lobelia siphilitica*)
Herbaceous perennial; tolerating inundation; blooms in July, August, September, October

New England Aster (*Symphyotrichum novae-angliae*)
Herbaceous perennial; tolerating inundation; blooms in August, September, October

The planter boxes are designed as an offline system to take runoff from storms no larger than 1 inch of rain in 24 hours. Therefore, a flow diversion or bypass mechanism must be installed in the downspout before the first planter box. The bypass pipe must be designed with capacity sufficient to convey the 100-year design storm runoff.

Step 5: Reduced Runoff Volume Calculations

The volume retained in the planter boxes is determined by the available water capacity of soil bed and sand layer, and the field capacity of the gravel layer. As stated above, the available water capacity is the difference between the field capacity and the wilting point. These values can be found in the table on Page 16. For this example, the wilting point, field capacity and available water capacity for the soil bed, sand and gravel layer are shown in the table found at the top of the next page:

Layer	Field Capacity (cf/cf)	Wilting Point (cf/cf)	Available Water Capacity (cf/cf)
Soil Bed (Silt Loam)	0.284	0.135	0.149
Sand	0.062	0.024	0.038
Gravel	0.02	-	0.02

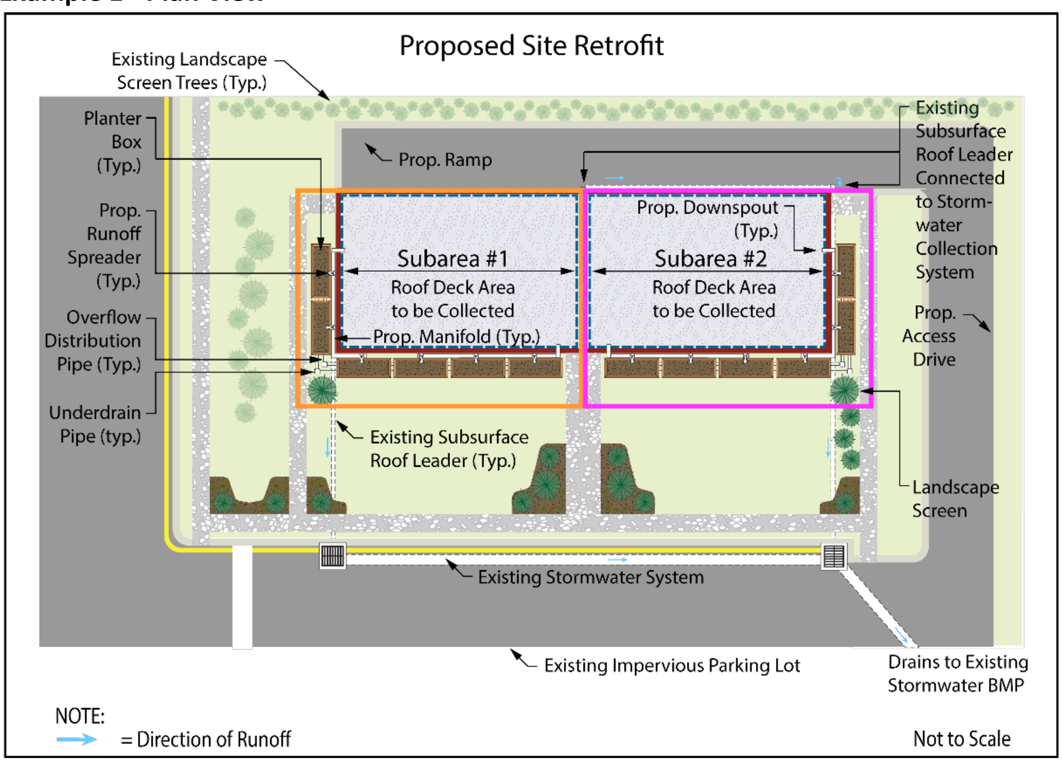
A factor of safety of 0.5 is applied to the available water capacity of the soil and sand. Therefore, the volume reduction provided by the planter boxes can be calculated from the product of the volume of the layers and the available water capacity. The result is shown below:

Layer	Layer Volume (= # of Units x L x W x D) (cf)	Available Water Capacity (cf/cf)	Runoff Retention Volume (cf)
Soil Bed	12 x 6 x 5 x 1.5 = 540	0.149 x 0.5 = 0.0745	40.23
Sand	12 x 6 x 5 x 0.5 = 180	0.038 x 0.5 = 0.019	3.42
Gravel	12 x 6 x 5 x 1 = 360	0.02	7.2
		Total =	**50.85**

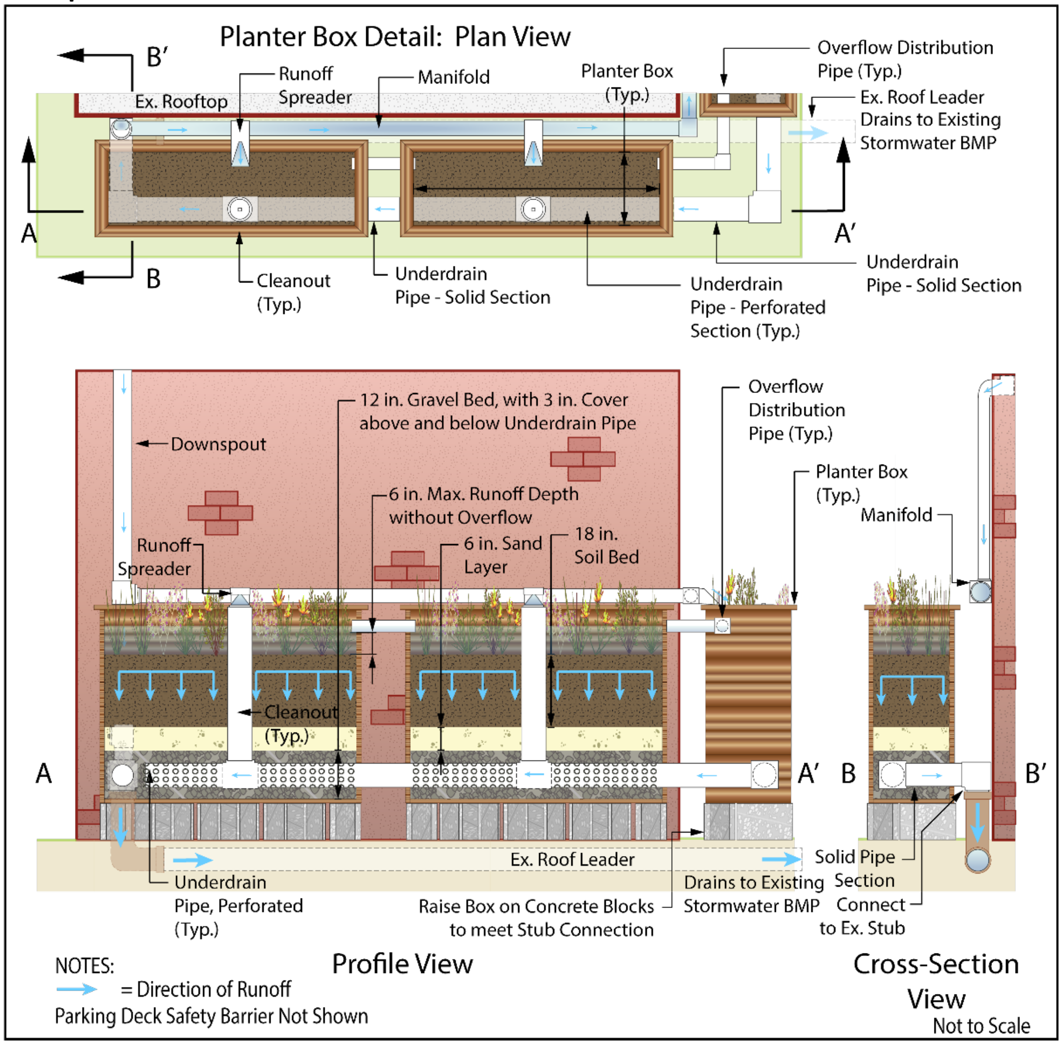
Therefore, the average volume reduction provided by the system is approximately 50.85 cf. This volume is subtracted from the 660 cf of runoff shown above to determine the volume of runoff leaving the site. This means that 609.15 cf of runoff would leave the site in this example.

Illustrations of the planter box system are found below and on the following page.

Example 1 - Plan View



Example 1 – Detail Views



Example 2: Parking Lot Rain Garden Designed to Infiltrate into the Subsoil

This example demonstrates how to design a rain garden as a parking lot island that collects runoff from a 0.25 acre asphalt parking area situated within a redevelopment area. The design storm to be infiltrated is the WQDS. Runoff generated by storms larger than the design storm will be conveyed across the surface of the rain garden to down-gradient stormwater catch basins which, in turn, discharge to the stormwater collection system. The following parameters apply:

Tested subsoil permeability rate	8 in/hr
Assumed soil bed design infiltration rate	10 in /hr
Soil Bed Depth =	24 in

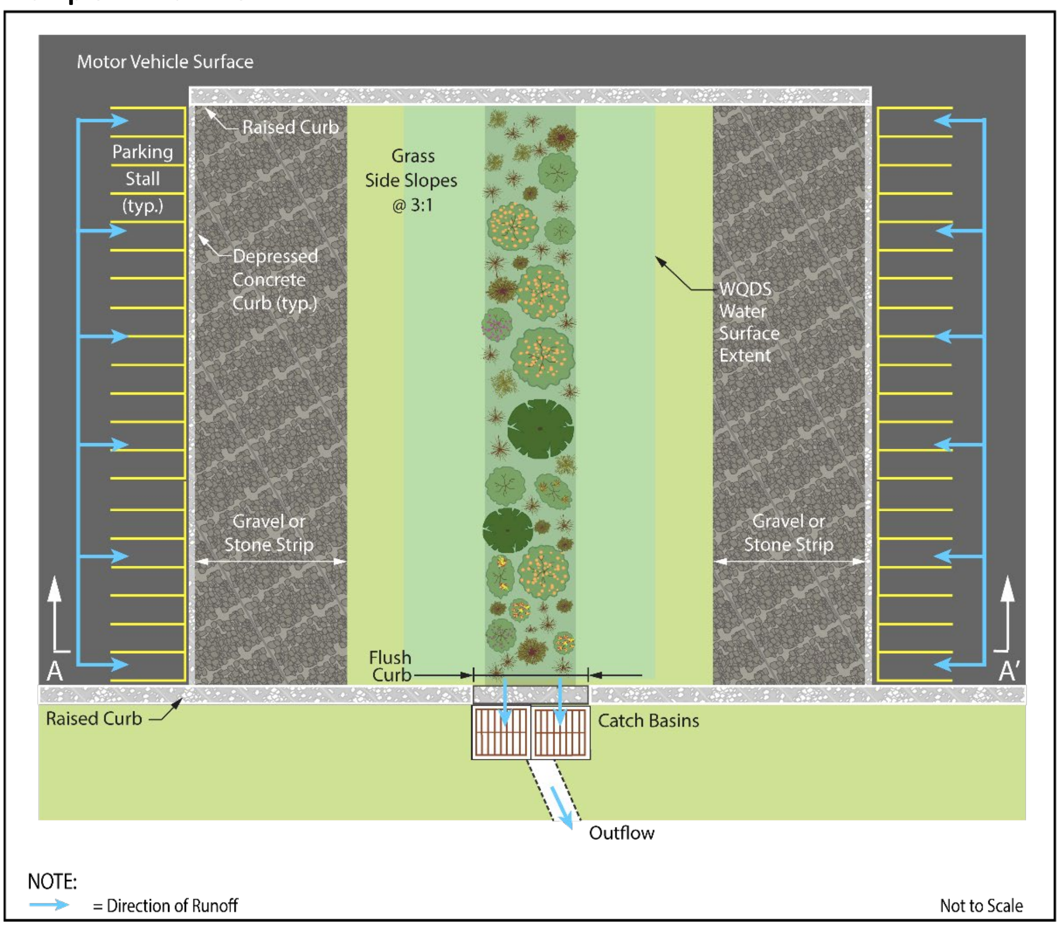
Step 1: Runoff Calculations

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 939 cf based upon an NRCS Curve Number (CN) of 98 for asphalt.

Step 2: Sizing of the Rain Garden

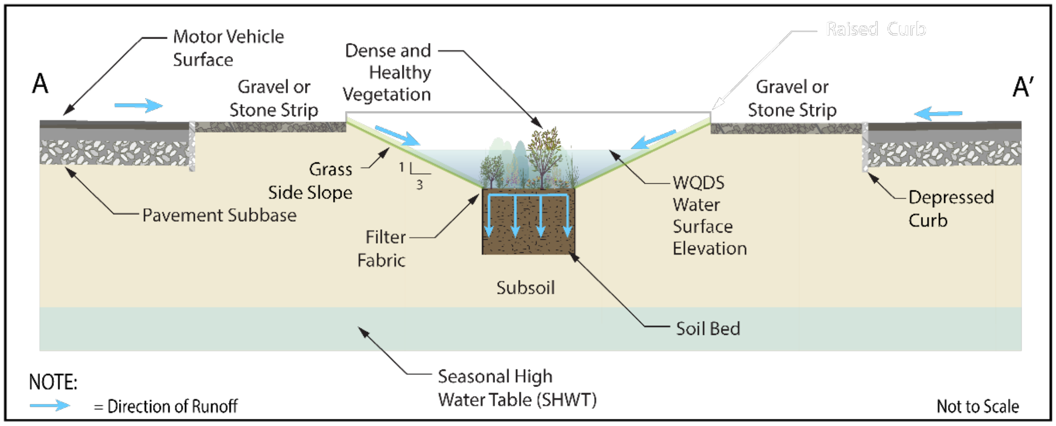
The rain garden is in the center of the parking area, separating two rows of parking spaces. A plan view of the design is provided below:

Example 2 - Plan View



A section view at the lower limit of the rain garden is shown below. For simplicity, fencing or another barrier to prevent vehicular intrusion into the system are omitted.

Example 2 - Section View



The rain garden is designed with grassed side slopes of 3:1 (horizontal distance to vertical distance) on the sides adjacent to the parking stalls. The footprint of the soil bed is 465 sf or 3 ft wide by 155 ft long. The width of the rain garden becomes 9 feet and 12 feet at the elevations of 1 foot and 1.5 feet above the soil bed.

The tested soil permeability rate of the subsoil is 8 in/hr. The design soil permeability will be 4 in/hr. Exfiltration is incorporated into the routing calculations for the rain garden and occurs only within the footprint of the soil bed within the rain garden. No exfiltration is allowed on the side slopes. Therefore, the exfiltration flow through the bottom of the rain garden shall not exceed the flow rate produced by multiplying the footprint of 465 sf with the design soil permeability of 4 in/hr, which results in a flow rate of 0.04 cfs. Note that a 5 ft wide gravel or stone strip, with a slope of no greater than 10 percent, is installed on the edge of pavement adjacent to the rain garden to provide pretreatment of the distributed inflow because exfiltration is used in the design calculation. The routing calculation for the proposed rain garden is performed to determine the required footprint. From the hydrograph, it is known that the maximum water level produced by the WQDS is 0.85 ft above the soil bed. Results for the WQDS are shown on the following page as reprints from a hydrologic modelling software package using the NRCS methodology.

WQDS Summary Report

```
Inflow Area =        10,890 sf,100.00% Impervious,  Inflow Depth =   1.03"   for  WQ event
Inflow      =      0.73 cfs @     1.11 hrs,  Volume=              939 cf
Outflow     =      0.04 cfs @     0.66 hrs,  Volume=              939 cf,  Atten= 95%,  Lag= 0.0 min
Discarded =        0.04 cfs @     0.66 hrs,  Volume=              939 cf
Primary     =      0.00 cfs @     0.00 hrs,  Volume=                0 cf

Routing by Stor-Ind method, Time Span= 0.00-48.00 hrs, dt= 0.01 hrs
Peak Elev= 0.85' @ 1.86 hrs   Surf.Area= 1,252 sf   Storage= 727 cf

Plug-Flow detention time= 158.0 min calculated for 939 cf (100% of inflow)
Center-of-Mass det. time= 158.0 min ( 228.3 - 70.3 )
```

Volume	Invert	Avail.Storage	Storage Description
#1	0.00'	1,744 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
0.00	465	0	0
1.00	1,395	930	930
1.50	1,860	814	1,744

Device	Routing	Invert	Outlet Devices
#1	Discarded	0.00'	**0.04 cfs Exfiltration at all elevations**
#2	Primary	0.85'	**4.0" Horiz. Orifice/Grate** C= 0.600 Limited to weir flow at low heads

Discarded OutFlow Max=0.04 cfs @ 0.66 hrs HW=0.02' (Free Discharge)
↑1=**Exfiltration** (Exfiltration Controls 0.04 cfs)

Primary OutFlow Max=0.00 cfs @ 0.00 hrs HW=0.00' (Free Discharge)
↑2=**Orifice/Grate** (Controls 0.00 cfs)

Source: HydroCAD® Summary Report; HydroCAD is a registered trademark of HydroCAD Software Solutions LLC. Used with permission.

WQDS Routing Table

Time (hours)	Inflow (cfs)	Elevation (feet)	Outflow (cfs)	Discarded (cfs)
0.00	0.00	0.00	0.00	0.00
0.10	0.00	0.00	0.00	0.00
0.20	0.00	0.00	0.00	0.00
0.30	0.00	0.00	0.00	0.00
0.40	0.00	0.00	0.00	0.00
0.50	0.02	0.00	0.01	0.01
0.60	0.04	0.01	**0.03**	**0.03**
0.70	0.05	0.02	**0.04**	**0.04**
0.80	0.07	0.03	0.04	0.04
0.90	0.16	0.08	0.04	0.04
1.00	0.46	0.22	0.04	0.04
1.10	**0.73**	0.49	0.04	0.04
1.20	**0.40**	0.69	0.04	0.04
1.30	0.19	0.76	0.04	0.04
1.40	0.11	0.79	0.04	0.04
1.50	0.10	0.81	0.04	0.04
1.60	0.08	0.82	0.04	0.04
1.70	0.07	0.83	0.04	0.04
1.80	0.07	**0.84**	0.04	0.04
1.90	0.03	**0.85**	0.04	0.04
2.00	0.02	0.84	0.04	0.04

Source: HydroCAD® Routing Table; HydroCAD is a registered trademark of HydroCAD Software Solutions LLC. Used with permission

Step 3: Check Drain Time

The soil bed permeability rate is 10 in/hr, but the subsoil design infiltration rate (1/2 the tested rate) is 4 in/hr. Therefore, the drain time must be calculated based on the subsoil design permeability rate. The area for infiltration is 465 sf. The infiltration rate is calculated to be:

$$Infiltration\ Rate = 465\ ft\ x\ \frac{4\ in/hr}{12\ in/ft} = 155\ \text{cf/hr}$$

For the WQDS producing 939 cf of stormwater runoff, the drain time is as follows:

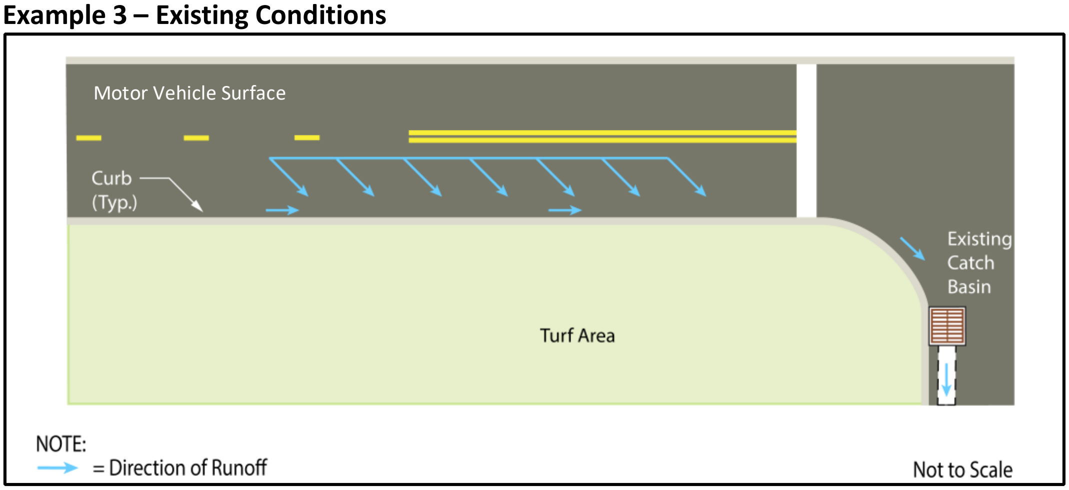
$$Drain\ Time = \frac{939\ cf}{155\ cf/hr} = 6.06\ \text{hr}$$

Note that the calculated drain time is less than the recommended 24-hour maximum for public areas exposed to pedestrian and vehicular traffic. A groundwater mounding analysis is required for all infiltration BMPs. The guidance for conducting a groundwater mounding analysis is available at *Chapter 13*. It is not shown here.

Example 3: For a new two-lane curbed roadway in an area outside the coastal plain, 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 =	0.25 ac of motor vehicle surface
Pavement NRCS Curve Number (CN) =	98
Soil Bed Depth =	18 in
Side Slope above Soil Bed =	3:1 (horizontal to vertical)
Tested Permeability of Soil Bed =	8 in/hr
Tested Permeability of Subsoil =	2 in/hr
Depth to the Seasonal High Water Table (SHWT) =	8 ft below existing ground level

Example 3 – 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 939 cf.

Step 2: Sizing the pretreatment

Because exfiltration is incorporated in the routing calculaiton, pretreatment is required. An MTD is incorporated down-gradient of the catch basin and before the runoff enters the proposed basin. The MTD must be sized to handle the flowrate of the WQDS, which is 0.74 cfs in this example. An MTD that has 50% TSS removal rate can be selected from the list of certified MTDs available at https://www.nj.gov/dep/stormwater/treatment.html.

In accordance with the design criteria for this type of system, the maximum depth of runoff above the surface of the soil bed is 1 ft. The exfiltration rate, 1 in/hr, is one half the tested soil permeability rate. By trial and error, a bioretention basin is designed with a 600 sf soil bed area, or "footprint,' and the depth of stormwater runoff is approximately 1 ft as the initial configuration. The side slopes are set at the limit of 3:1 (horizontal to vertical) above the soil bed. Assuming the soil bed is 6 ft wide and 100 ft long resulting in 600 sf of footprint of the basin. The surface area will be 1200 sf (100 ft by 12 ft) and 1500 sf (100 ft by 15 ft) due to the side slope, at 1 and 1.5 ft above the basin bottom, respectively. Exfiltration is allowed only within the footprint of the basin. No exfiltration is allowed on the side slopes. Therefore, the exfiltration flow through the bottom of the basin shall not exceed the flow rate produced by multiplying the footprint 600 sf with the design soil permeability 1 in/hr, which results in a flow rate of 0.01 cfs through the footprint of the basin. The hydrograph shows that the stormwater runoff in the basin during the WQDS reaches 0.98 ft above the soil bed. The depth of stormwater runoff generated is less than the maximum allowable depth of 1 ft. A riser with an orifice diameter of 6 inches is designed at an invert at 0.98 feet above the soil bed to bypass the stormwater runoff generated by storms larger than the WQDS.

The routing table is shown to the right, with the summary report depicted on the next page.

Routing Table

Time (hours)	Inflow (cfs)	Elevation (feet)	Outflow (cfs)	Discarded (cfs)
0.00	0.00	0.00	0.00	0.00
0.10	0.00	0.00	0.00	0.00
0.20	0.00	0.00	0.00	0.00
0.30	0.00	0.00	0.00	0.00
0.40	0.00	0.00	0.00	0.00
0.50	0.02	0.01	0.00	**0.00**
0.60	0.04	0.02	0.01	**0.01**
0.70	0.05	0.04	0.01	0.01
0.80	0.07	0.07	0.01	0.01
0.90	0.16	0.12	0.01	0.01
1.00	0.46	0.25	0.01	0.01
1.10	**0.73**	0.52	0.01	0.01
1.20	**0.40**	0.74	0.01	0.01
1.30	0.19	0.83	0.01	0.01
1.40	0.11	0.87	0.01	0.01
1.50	0.10	0.90	0.01	0.01
1.60	0.08	0.92	0.01	0.01
1.70	0.07	0.95	0.01	0.01
1.80	0.07	0.97	0.01	0.01
1.90	0.03	0.98	0.01	0.01
2.00	0.02	**0.98**	**0.01**	0.01
2.10	0.01	**0.98**	**0.01**	0.01
2.20	0.00	0.98	0.01	0.01
2.30	0.00	0.98	0.01	0.01
2.40	0.00	0.98	0.01	0.01
2.50	0.00	0.97	0.01	0.01

Source: HydroCAD® Routing Table; HydroCAD is a registered trademark of HydroCAD Software Solutions LLC. Used with permission.

WQDS Summary Table

Inflow Area = 10,890 sf,100.00% Impervious, Inflow Depth = 1.03" for WQ event
Inflow = 0.73 cfs @ 1.11 hrs, Volume= 939 cf
Outflow = 0.01 cfs @ 2.09 hrs, Volume= 939 cf, Atten= 99%, Lag= 59.3 min
Discarded = 0.01 cfs @ 0.59 hrs, Volume= 939 cf
Primary = 0.00 cfs @ 2.09 hrs, Volume= 0 cf

Routing by Stor-Ind method, Time Span= 0.00-48.00 hrs, dt= 0.01 hrs
Peak Elev= 0.98' @ 2.09 hrs Surf.Area= 1,190 sf Storage= 880 cf

Plug-Flow detention time= 742.4 min calculated for 939 cf (100% of inflow)
Center-of-Mass det. time= 742.5 min (812.8 - 70.3)

Volume	Invert	Avail.Storage	Storage Description
#1	0.00'	1,575 cf	**Custom Stage Data (Prismatic)** Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)
0.00	600	0	0
1.00	1,200	900	900
1.50	1,500	675	1,575

Device	Routing	Invert	Outlet Devices
#1	Discarded	0.00'	**0.01 cfs Exfiltration at all elevations**
#2	Primary	0.98'	**6.0" Vert. Orifice/Grate** C= 0.600

Discarded OutFlow Max=0.01 cfs @ 0.59 hrs HW=0.02' (Free Discharge)
└**1=Exfiltration** (Exfiltration Controls 0.01 cfs)

Primary OutFlow Max=0.00 cfs @ 2.09 hrs HW=0.98' (Free Discharge)
└**2=Orifice/Grate** (Orifice Controls 0.00 cfs @ 0.20 fps)

Source: HydroCAD® Summary Report; HydroCAD is a registered trademark of HydroCAD Software Solutions LLC. Used with permission.

Step 3: Estimated Drain Time Calculation

For this step, the time it takes to drain the collected stormwater runoff below the surface of the soil bed must be calculated to verify it is less than the maximum of 72 hours. 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. For the WQDS, the drain time is calculated as follows:

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

$$= \frac{939\ cf}{(600\ sf\ x\ 1\ in/hr\ x\ 1\ ft/12\ in)} = 18.78\ \text{hr}$$

Since 18.78 hr is less than the allowable maximum drain time of 72 hr, the small-scale 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 separation requirement. By inspection, the sum of the 1.5 ft basin depth and the 1.5 ft soil bed depth equals a lowest point of the basin depth of 3 ft below the existing ground level. As stated previously, the SHWT is 8 ft below ground level. The elevation difference between the basin bottom and the SHWT is 5 ft, which is greater than the 2 ft mimimum separation requirement.

Step 5: Groundwater Mounding Analysis

Calculate the height of the groundwater mounding caused by the infiltration of stormwater runoff to ensure that doing so will neither impact the system, meaning prevent infiltration, nor impact nearby structures. For information on conducting a groundwater mounding analysis, see *Chapter 13*. For this example, the recharge rate is the design permeability rate of 1.0 in/hr. The horizontal hydraulic conductivity is also 1 in/hr since the site is outside the coastal plain. One-half of the length and width of the soil bed area, 50 and 3 ft, respectively, are the values to be input for x and y. The duration of infiltration period, for analyzing the WQDS, is the drain time, 18.78 hr, as calculated in Step 3. The results calculated by using the *Hantush Spreadsheet* are shown below.

Example 3: Input Section of the *Hantush Spreadsheet* and Calculated Δh(max)

	A	B	C	D	E	F	G	H	I	J	K
6	Input Values										
7	*1.00*	*R*		Recharge rate (permeability rate) (in/hr)							
8	*0.150*	Sy		Specific yield, Sy (dimensionless) default value is 0.15; max value is 0.2 provided that a lab test data is submitted							
9	1.00	Kh		Horizontal hydraulic conductivity (in/hr) Kh = 5xRecharge Rate (R) in the costal plan; Kh=R outside the coastal plan							
10	50.000	x		1/2 length of basin (x direction, in feet)							
11	3.000	y		1/2 width of basin (y direction, in feet)							
12	18.78	t		Duration of infiltration period (hours)							
13	10.00	hi(0)		Initial thickness of saturated zone (feet)							
14											
15	12.861	h(max)		Maximum thickness of saturated zone (beneath center of basin at end of infiltration period)							
16	2.861	Δh(max)		Maximum groundwater mounding (beneath center of basin at end of infiltration period)							

The SHWT is 8.0 ft below the basin bottom. The maximum mounding height is 2.861 ft above the SHWT, meaning the highest point of the mounding is located 5.139 ft below ground level. The bottom of the soil bed is 3 feet below the ground level. Therefore, the temporarily increased elevation in the groundwater level, produced by infiltrating stormwater runoff generated by the WQDS, will not interfere with the drainage of the proposed bioretention system.

Step 6: Overflow Configuration

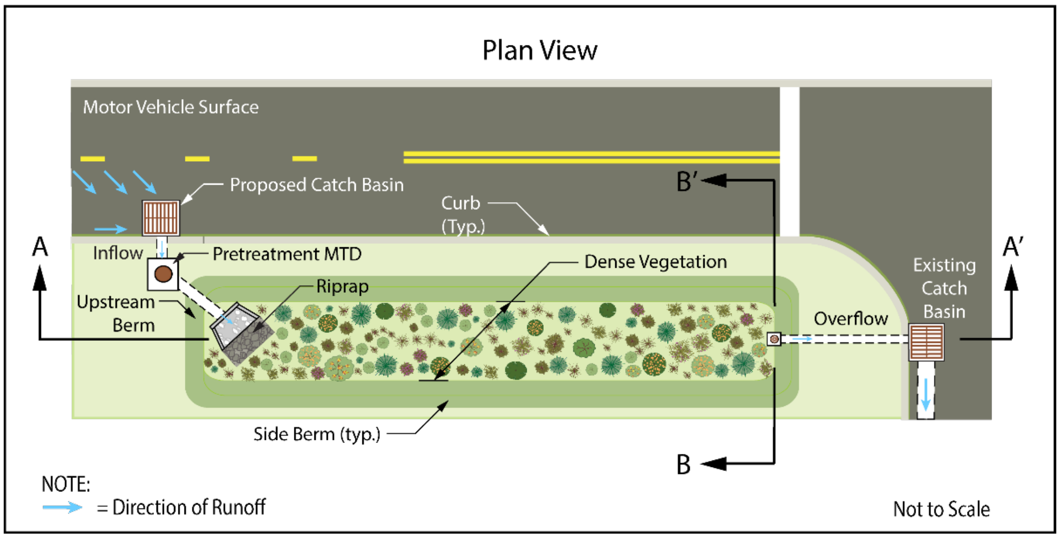
The small-scale bioretention system in this example is an on-line system. On-line systems receive runoff from all storms events and they convey the runoff from larger storms through an overflow, which, in this example, consists of a berm and an overflow riser. The opening in the riser is set at an elevation 1 ft above the surface of the soil bed; this design allows the accumulation of runoff up to the elevation of stormwater runoff generated by the WQDS 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

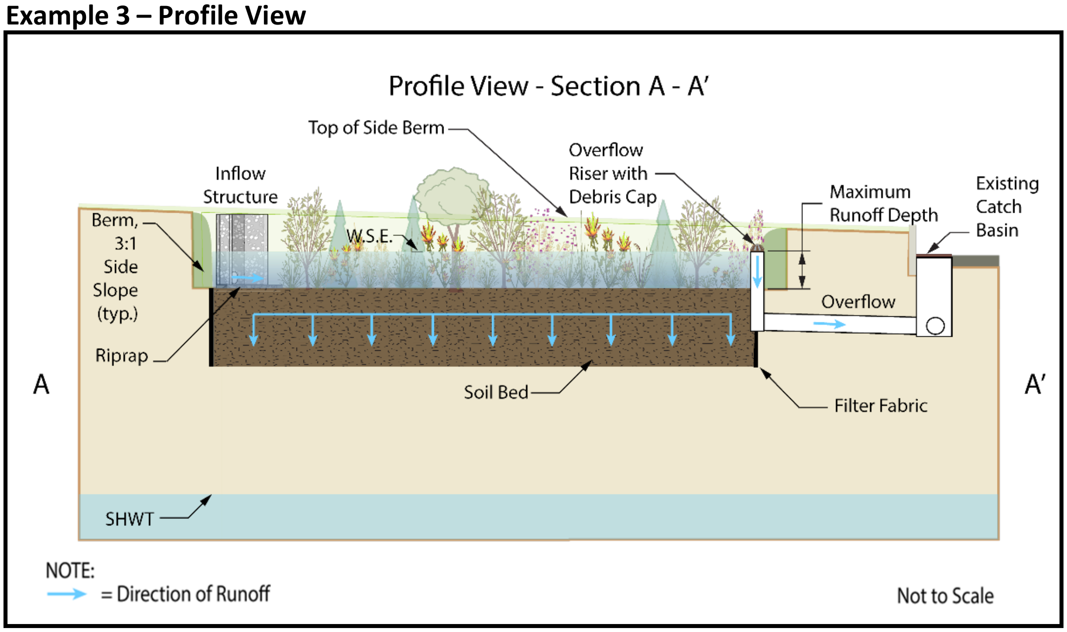
The small-scale bioretention system in this example includes earthen embankments. Therefore, the overall size of the system will have to account for the required 3:1 minimum side slopes. As-built testing must be conducted to validate the permeability rate of the soil bed, confirm the design permeability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

The following illustrations show this small-scale 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.

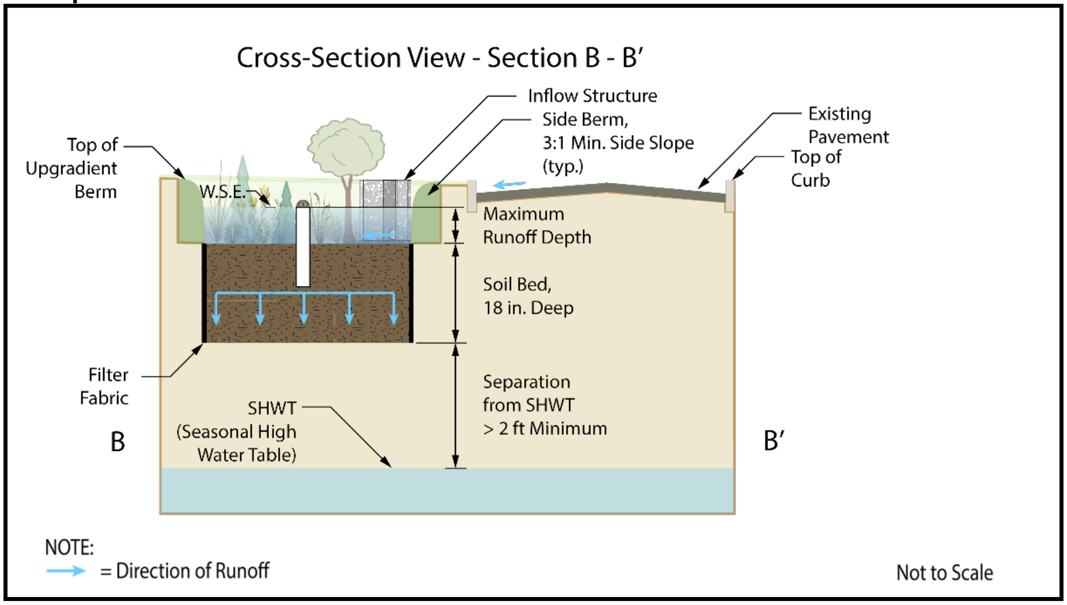
Example 3 – Plan View



Example 3 – Profile View



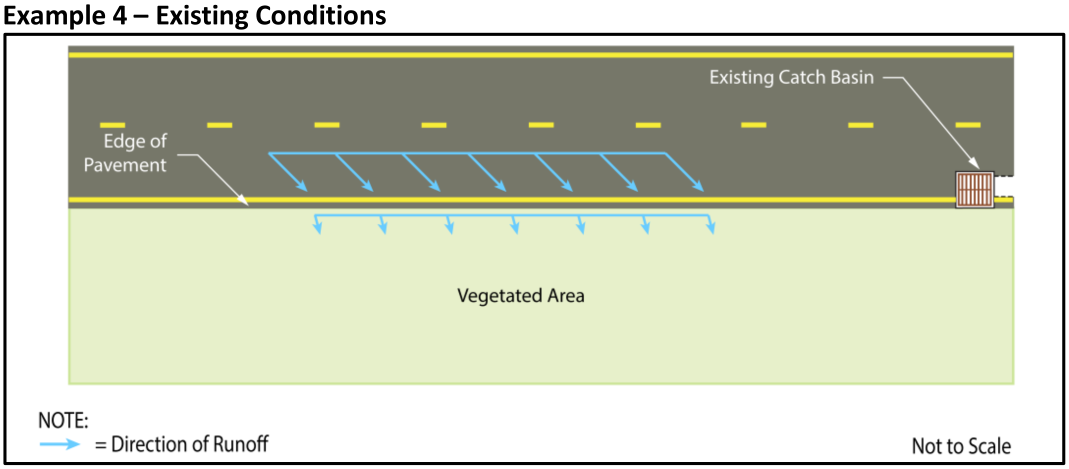
Example 3 – Cross-Section View



Example 4: For the existing uncurbed section of motor vehicle surface illustrated below, design a small-scale 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 =	5,000 sf of paved road surface
Pavement NRCS Curve Number (CN) =	98
Soil Bed Depth =	18 in
Assumed Design Permeability of Soil Bed =	4 in/hr
WQDS Depth =	18 in = 1.5 ft

Example 4 – Existing Conditions



Step 1: Runoff Calculations

Using the NRCS Methodology described in National Engineering Handbook, Part 630 (NEH) and discussed in *Chapter 5: Stormwater Runoff Water Quantity Standards and Computations*, the WQDS stormwater runoff volume is calculated to be 431 cf.

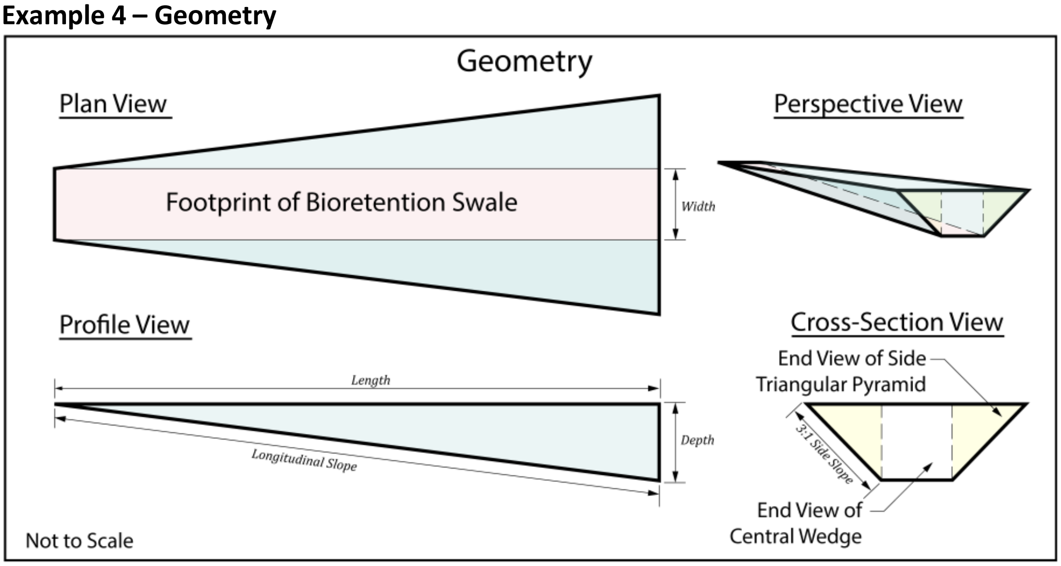
Step 2: Preliminary Shape and Size of the Bioretention Swale

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:

$$Surface\ Area = \frac{431\ cf}{(0.5\ x\ 1.5\ ft)} = 575 \text{ sf}$$

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 4 – 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 3, an estimate of the drain time for the Water Quality Design Storm would be calculated as follows:

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

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:

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

$$= \frac{18\ in}{4\ in/hr} = 4.5\text{ hr}$$

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

Step 4: Overflow Configuration

The small-scale 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 Water Quality Design Storm 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

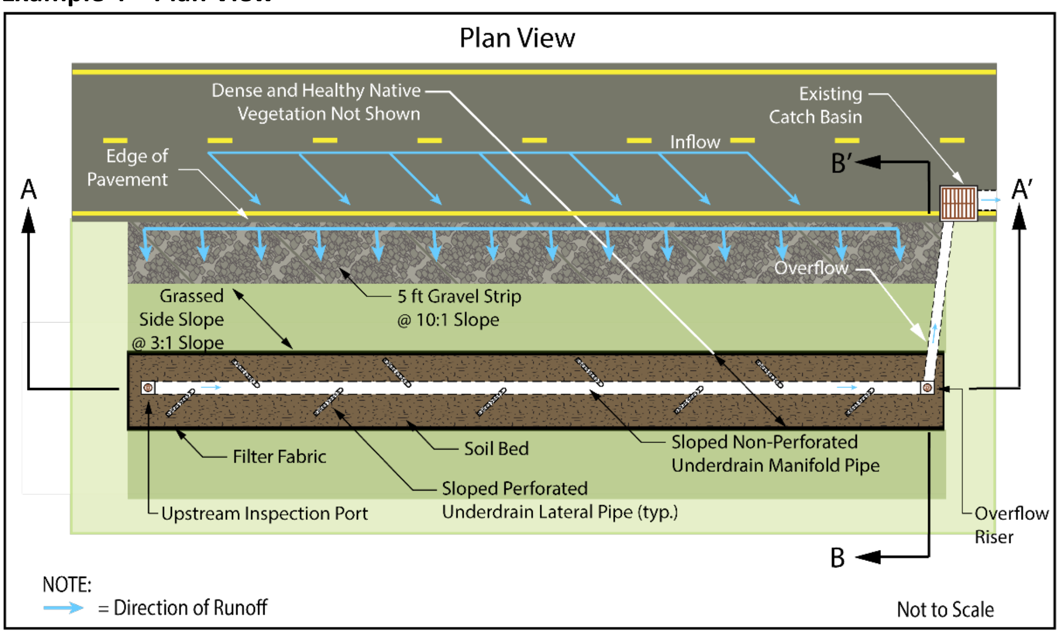
The vertical distance between the lowest elevation of the gravel layer and the SHWT must be checked to ensure it meets the minimum 1 ft separation requirement.

Step 7: Refinements to the Design

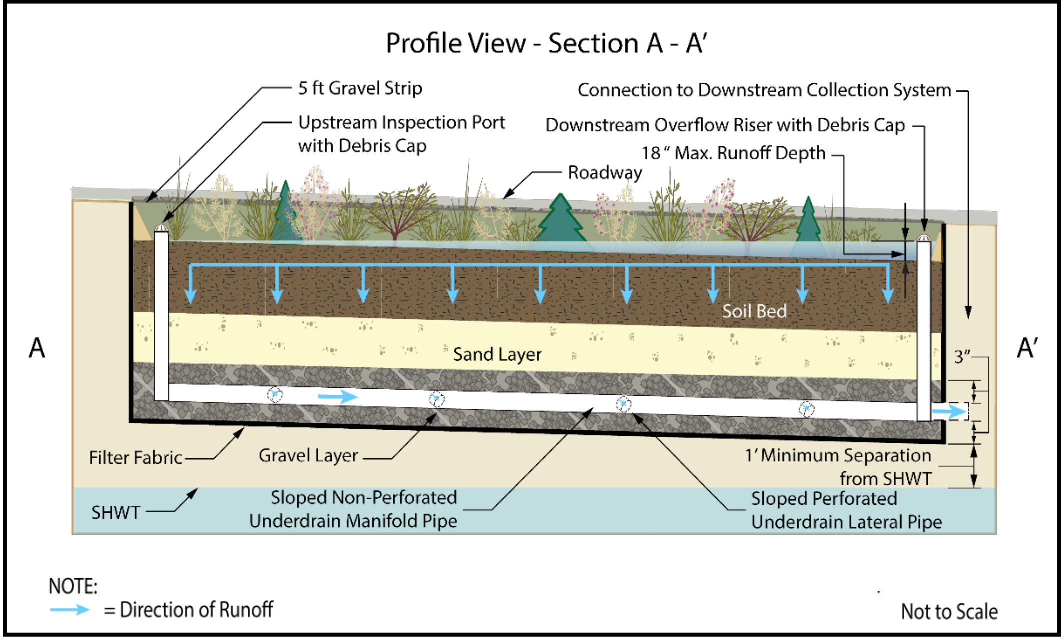
The overall size of the system will have to account for the two triangular pyramids on the sides which have a 3:1 slope. Additionally, the 5 ft wide gravel apron is placed between the bioretention swale and the edge of pavement to prevent erosion. Prior to installation of the soil bed, permeability testing is not feasible; therefore, for design calculations, a permeability rate of 4 in/hr was assumed. This assumed permeability rate included the required factory of safety, which translates to an assumed tested permeability rate of 8 in/hr. 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 two pages show this small-scale 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 down-gradient 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.

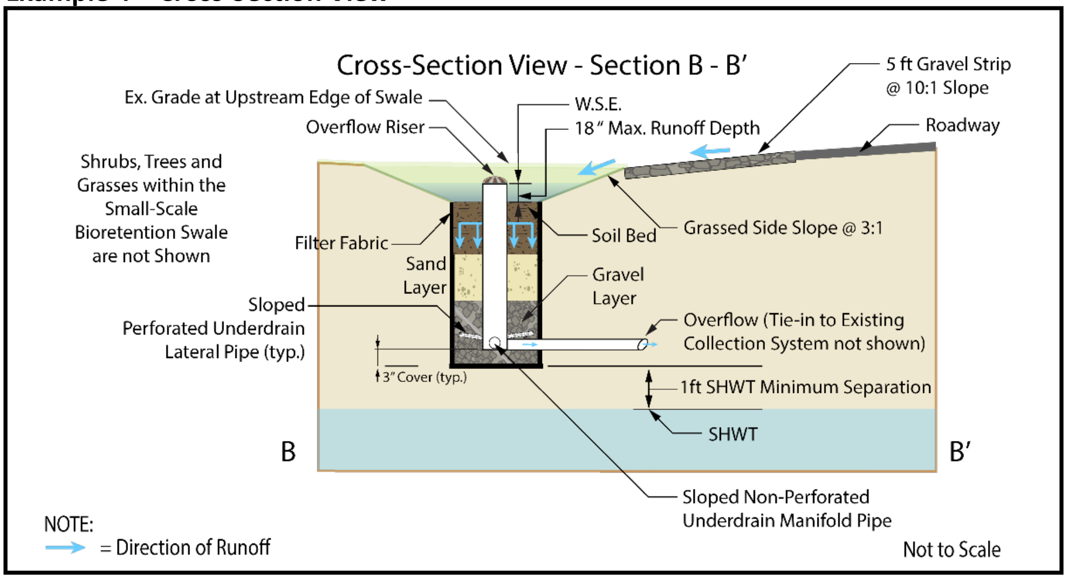
Example 4 – Plan View



Example 4 – Profile View



Example 4 – Cross-Section View



Considerations

When planning a small-scale 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 Water Quality Design Storm 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 small-scale 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 small-scale 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 small-scale 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 small-scale bioretention system by reducing incoming velocities and capturing coarser sediments. Note that pretreatment is not optional for small-scale bioretention systems designed to infiltrate into the subsoil that include exfiltration in the stormwater routing calculations.

- 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 small-scale 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 small-scale 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 should 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 should be given to issues such as scour and floatation of the mulch during large storm events.

Enhancing Pollutant Removal

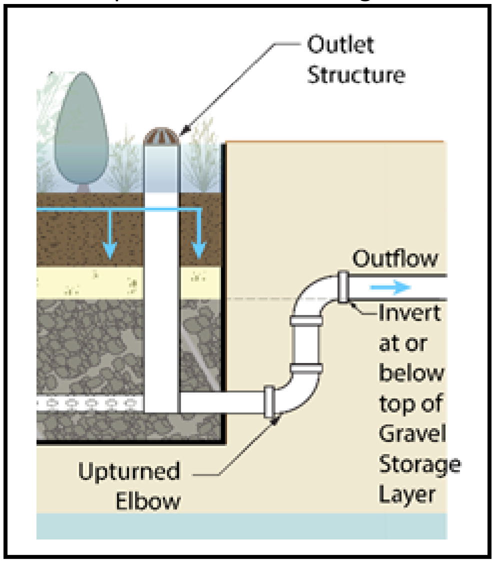
- Maximizing the horizontal distance between inflow and overflow structures in a small-scale bioretention system may increase contact time for stormwater runoff with the system vegetation and soil bed, where pollutant-removing chemical and biological processes occur. Grouping inflows near outflows may 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 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 small-scale 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.

Vegetation

- When selecting vegetation, the designer should consider the aesthetic appearance of the vegetation in different seasons. Refer to the table on the following pages for additional information on the bloom period of plants that may be incorporated into a small-scale bioretention system. These perennial plants are suited to frequent inundation.

- Location of a small-scale bioretention system is an important factor when selecting vegetation. The following factors should be considered:
    - Small-scale bioretention systems near buildings or large trees that result in shading will require different vegetation than a small-scale bioretention system that receives full sun. This is particularly important in large small-scale bioretention systems because sunlight duration may vary widely from one section to another.
    - Overhangs that prevent precipitation from falling directly on vegetation may adversely impact growth and survival; therefore, these areas should be avoided when determining small-scale bioretention system locations.
    - When designing a small-scale bioretention system that will include trees, care should be taken to prevent inadvertent damage to the tree roots, which can be fatal. Otherwise, new roots may inadvertently spread into or under adjacent structures. One scenario that will cause root damage, or even tree death, is by the placement of additional plants and landscape materials, not part of the original design, within the confines of a tree pit. This results in accidental smothering by starving the roots of soil moisture and halting the free exchange of gases throughout the root zone. Nearby utility work or excavation may also damage tree roots. Using structural soil, which is stone aggregate whose voids are filled with soil that can be mixed with a moisture retaining gel to provide a matrix for sustainable root growth, and including a geogrid as a permeable cover on top of this structural soil, may be one . The added strength of this mixture reduces the likelihood of damage to the tree by nearby utility work.

Bloom Information for Various Small-scale Bioretention System Plants						
Common Name	**Genus**	**Species**	**Height**	**Bloom Color**	**Bloom Start**	**Bloom End**
Spicebush, Wild allspice	*Lindera*	*benzoin*	6 – 12’	white, yellow	April	April
Marsh marigold, Yellow marsh marigold, Cowslip	*Caltha*	*palustris*	1 – 3’	yellow	April	May
Kinnikinnick, Red bearberry	*Arctostaphylos*	*uva-ursi*	1 – 3’	white, pink	March	June
Common Winterberry	*Ilex*	*verticillata*	6 – 12’	white flowers, red berries	April	July
Highbush blueberry	*Vaccinium*	*corymbosum*	6 – 12’	pink, white	May	June
Arrowwood	*Viburnum*	*dentatum*	6 – 12’	white	May	July
Harlequin blueflag, Northern blue flag, Large blue iris	*Iris*	*versicolor*	1 – 3’	blue, purple	May	August
Sweet fern	*Comptonia*	*peregrina*	3 – 6’	white, green	May	August
Deertongue	*Dichanthelium*	*clandestinum*	3 – 6’	green stems	May	September
Cardinal flower	*Lobelia*	*Cardinalis*	3 – 6’	red	May	October
Allegheny monkeyflower, Monkeyflower, Square-stemmed monkeyflower	*Mimulus*	*ringens*	1 – 3’	blue, purple	June	September
Common Buttonbush	*Cephalanthus*	*occidentalis*	6 – 12’	white, pink	June	September
Inkberry	*Ilex*	*glabra*	6 – 12’	white flowers, black berries	June	September
Woolgrass, Cottongrass bulrush	*Scirpus*	*cyperinus*	3 – 6’	green, brown	June	September
Swamp milkweed, Pink milkweed	*Asclepias*	*incarnata*	3 – 6’	pink, purple	June	October
Blue vervain, Swamp verbena	*Verbena*	*hastata*	3 – 6’	blue, purple	June	October
Clethra, Summersweet	*Clethra*	*alnifolia*	3 – 6’ 6 – 12’	white, pink	July	August
Beggar's tick sunflower, Devil's beggartick, Spanish needles	*Bidens*	*frondosa*	0 – 1’ 1 – 3’	yellow	July	August
American tiger lily, Turk's cap lily, Swamp lily	*Lilium*	*superbum*	3 – 6’	red, orange, yellow	July	September

Legend: Shrub | Grass or Sedge | Herb

Bloom Information for Various Small-scale Bioretention System Plants (*cont'd.*)						
Common Name	**Genus**	**Species**	**Height**	**Bloom Color**	**Bloom Start**	**Bloom End**
Common threesquare, American bulrush	*Schoenoplectus*	*pungens*	3 – 6'	brown spikelets	July	September
Joe Pye weed, Trumpetweed,	*Eutrochium*	*fistulosum*	3 – 6' 6 – 12'	pink, purple	July	September
Purple Joe Pye weed Sweet Joe Pye weed	*Eutrochium*	*purpureum*	3 – 6'	pink, purple	July	September
Turtlehead, White turtlehead	*Chelone*	*glabra*	3 – 6'	white, pink	July	September
Northern Bayberry	*Morella*	*pennsylvanica*	6 – 12'	yellow flowers, blueish white berries	July	October
Common sneezeweed, Fall sneezeweed, Autumn sneezeweed	*Helenium*	*autumnale*	1 – 3' 3 – 6'	yellow	July	October
Cutleaf coneflower, Green-headed coneflower	*Rudbeckia*	*laciniata*	3 – 6'	yellow	July	October
Great blue lobelia	*Lobelia*	*siphilitica*	1 – 3'	blue	July	October
New York aster	*Symphyotrichum*	*novi-belgii*	3 – 6'	blue	July	October
Roundleaf goldenrod	*Solidago*	*patula*	3 – 6'	yellow	July	October
New York ironweed	*Vernonia*	*novaboracensis*	3 – 6'	red, purple	August	September
Lowland broomsedge, Bushy bluestem	*Andropogon*	*glomeratus*	3 – 6'	white, brown	August	November
New England aster, New England American aster	*Symphyotrichum*	*novae-angliae*	3 – 6'	pink, purple	August	October
Switchgrass	*Panicum*	*Virgatum*	3 – 6'	green, brown	August	November
Wrinkleleaf goldenrod, Wrinkle-leaf goldenrod, Rough-leaved goldenrod	*Solidago*	*rugosa*	3 – 6'	yellow	September	September
Witch hazel	*Hamemelis*	*virginiana*	6 – 12'	orange, yellow	September	December

Legend: Shrub | Grass or Sedge | Herb

Maintenance

Regular and effective maintenance is crucial to ensure effective small-scale bioretention system performance. 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. Detailed inspection and maintenance logs must be maintained.

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 must take place when all 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 small-scale 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 small-scale 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 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 growing season.

- Grasses within the small-scale 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 should 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 significantly different from 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 Water Quality Design Storm 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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